Technical Support Document for One Total Maximum Daily Load for Indicator Bacteria in Caney Creek

Assessment Unit: 1010_03

Caney Creek at TCEQ monitoring Station 11335

By Todd Adams and Jimmy Millican
Texas Institute for Applied Environmental Research
Submitted to TCEQ November 2021

Published by the Texas Commission on Environmental Quality
AS-463, March 2022

Prepared for:
Total Maximum Daily Load Program
Texas Commission on Environmental Quality
MC-203
P.O. Box 13087
Austin, Texas 78711-3087

Prepared by:
Todd Adams
Jimmy Millican
Texas Institute for Applied Environmental Research
Tarleton State University
Stephenville, Texas

TIAER Publication TR2107
Submitted to TCEQ November 2021

Published by the Texas Commission on Environmental Quality as
AS-463 March 2022

Suggested citation:
Adams, Todd, and Jimmy Millican. Texas Institute for Applied Environmental Research 2021. Technical Support Document for One Total Maximum Daily Load for Indicator Bacteria in Caney Creek. Austin: Texas Commission on Environmental Quality (AS-463).

Acknowledgements

Financial support for this study was provided by the United States Environmental Protection Agency and the Texas Commission on Environmental Quality (TCEQ). The lead agency for this study was TCEQ. The administrative oversight, technical input, and review of this document by the TCEQ Project Manager, Mr. Jason Leifester, were important to the completion of this project and the development of this document.

Contents

Figures

Tables

Abbreviations

AU	assessment unit
cfs	cubic feet per second
cfu	colony forming units
CFR	Code of Federal Regulations
DAR	drainage-area ratio
DMU	Deer Management Unit
DSLP	days since last precipitation
E. coli	*Escherichia coli*
EPA	(United States) Environmental Protection Agency
FDA_{SWP}	fractional drainage area stormwater permit
FDC	flow duration curve
FG	future growth
I&I	inflow and infiltration
ISD	independent school district
LA	load allocation
LDC	load duration curve
MCM	minimum control measure
MGD	million gallons per day
mL	milliliter
MOS	margin of safety
MS4	municipal separate storm sewer system
MSGP	multi-sector general permit
MUD	Municipal Utility District
NLCD	National Land Cover Database
NOAA	National Oceanic and Atmospheric Administration
NPDES	National Pollutant Discharge Elimination System
NRCS	Natural Resources Conservation Service
OSSF	on-site sewage facility
SSO	sanitary sewer overflow
SWMP	stormwater management program
SWQM	surface water quality monitoring
TCEQ	Texas Commission on Environmental Quality
TMDL	total maximum daily load

TPDES	Texas Pollutant Discharge Elimination System
TPWD	Texas Parks and Wildlife Department
TWDB	Texas Water Development Board
USCB	United States Census Bureau
USDA	United States Department of Agriculture
USGS	United States Geological Survey
WLA	wasteload allocation
WLA_{SW}	wasteload allocation stormwater
WLA_{WWTF}	wasteload allocation wastewater treatment facilities
WUG	Water User Group
WWTF	wastewater treatment facility

Section 1. Introduction

1.1. Background

Section 303(d) of the federal Clean Water Act requires all states to identify waters that do not meet, or are not expected to meet, applicable water quality standards. States must develop a total maximum daily load (TMDL) for each pollutant that contributes to the impairment of a water body included on a state's 303(d) list of impaired waters. The Texas Commission on Environmental Quality (TCEQ) is responsible for ensuring that TMDLs are developed for impaired surface waters in Texas.

A TMDL is like a budget—it determines the amount of a particular pollutant that a water body can receive and still meet applicable water quality standards. TMDLs are the best possible estimates of the assimilative capacity of the water body for a pollutant under consideration. A TMDL is commonly expressed as a load with units of mass per period of time, but may be expressed in other ways. In addition to the TMDL an implementation plan is developed, which is a description of the regulatory and voluntary measures necessary to improve water quality and restore full use of the water body.

The TMDL Program is a major component of Texas' overall process for managing the quality of its surface waters. The program addresses impaired or threatened streams, reservoirs, lakes, bays, and estuaries (water bodies) in, or bordering on, the state of Texas. The program's primary objective is to restore and maintain water quality uses—such as drinking water supply, recreation, support of aquatic life, or fishing—of impaired or threatened water bodies.

TCEQ first identified the bacteria impairment within assessment unit (AU) 1010_03 of Caney Creek Segment 1010 in the *2018 Texas Integrated Report of Surface Water Quality for Clean Water Act Sections 305(b) and 303(d) List* (Texas Integrated Report; TCEQ, 2019a). The impairment was identified again in the 2020 Texas 303(d) List, the latest United States Environmental Protection Agency (EPA)-approved edition (TCEQ, 2020a). TCEQ first identified bacteria impairments to other AUs of Caney Creek in the 2006 Texas Integrated Report (TCEQ, 2007).

This document will consider a bacteria impairment in one AU of Caney Creek, Segment 1010. The impaired water body and identifying AU is:

- Caney Creek AU 1010_03

In this report, the impaired water body will be referred to as Caney Creek AU 1010_03 or 1010_03. The phrase "TMDL subwatershed" will refer to only the direct drainage area of impaired AU 1010_03.

1.2. Water Quality Standards

To protect public health, aquatic life, and development of industries and economies throughout Texas, TCEQ established the *Texas Surface Water Quality Standards* (TCEQ, 2018a). The Standards describe the limits for indicators that are monitored to assess the quality of available water for specific uses. TCEQ monitors and assesses water bodies based on these standards and publishes the Texas Integrated Report list biennially.

The Standards are rules that do all of the following:

- Designate the uses, or purposes, for which the state's water bodies should be suitable.
- Establish numerical and narrative goals for water quality throughout the state.
- Provide a basis on which TCEQ regulatory programs can establish reasonable methods to implement and attain the state's goals for water quality.

Standards are established to protect uses assigned to water bodies. The primary uses assigned to water bodies are:

- aquatic life use
- contact recreation
- domestic water supply
- general use

Fecal indicator bacteria are used to assess the risk of illness during contact recreation (e.g., swimming) from ingestion of water. Fecal indicator bacteria are bacteria that are present in the intestinal tracts of humans and other warm-blooded animals. The presence of these bacteria in water indicates that associated pathogens from fecal waste may be reaching water bodies because of such sources as inadequately treated sewage, improperly managed animal waste from livestock, pets, aquatic birds, wildlife, and failing septic systems (TCEQ, 2018b). The fecal indicator bacteria used for freshwater in Texas is *Escherichia coli* (*E. coli*), a species of fecal coliform bacteria.

On February 7, 2018, TCEQ adopted revisions to the *Texas Surface Water Quality Standards* (TCEQ, 2018) and on May 19, 2020, the EPA approved the categorical levels of recreational use and their associated criteria. Recreational use consists of five categories:

- **Primary contact recreation 1** – Activities that are presumed to involve a significant risk of ingestion of water (e.g., wading by children, swimming, water skiing, diving, tubing, surfing, handfishing, and the following whitewater activities: kayaking, canoeing, and rafting). It has a geometric mean criterion for *E. coli* of 126 colony forming units (cfu) per 100 milliliters (mL) and an additional single sample criterion of 399 cfu per 100 mL.

- **Primary contact recreation 2** – Water recreation activities, such as wading by children, swimming, water skiing, diving, tubing, surfing, handfishing, and whitewater kayaking, canoeing, and rafting that involve a significant risk of ingestion of water but that occur less frequently than for primary contact recreation 1 due to physical characteristics of the water body or limited public access. The geometric mean criterion for *E. coli* is 206 cfu per 100 mL.
- **Secondary contact recreation 1** – Activities that commonly occur but have limited body contact incidental to shoreline activity (e.g., fishing, canoeing, kayaking, rafting, and motor boating). These activities are presumed to pose a less significant risk of water ingestion than primary contact recreation 1 or 2 but more than secondary contact recreation 2. The geometric mean criterion for *E. coli* is 630 cfu per 100 mL.
- **Secondary contact recreation 2** – Activities with limited body contact incidental to shoreline activity (e.g., fishing, canoeing, kayaking, rafting, and motor boating) that are presumed to pose a less significant risk of water ingestion than secondary contact recreation 1. These activities occur less frequently than secondary contact recreation 1 due to physical characteristics of the water body or limited public access. The geometric mean criterion for *E. coli* is 1,030 cfu per 100 mL.
- **Noncontact recreation** – Activities that do not involve a significant risk of water ingestion, such as those with limited body contact incidental to shoreline activity, including birding, hiking, and biking. Noncontact recreation use may also be assigned where primary and secondary contact recreation activities should not occur because of unsafe conditions, such as ship and barge traffic. The geometric mean criterion for *E. coli* is 2,060 cfu per 100 mL.

Caney Creek AU 1010_03 has a presumed primary contact recreation 1 use with the associated *E. coli* geometric mean criterion of 126 cfu per 100 mL and single sample criterion of 399 cfu per 100 mL.

1.3. Report Purpose and Organization

The Caney Creek AU 1010_03 TMDL project was initiated through a contract between TCEQ and Texas Institute for Applied Environmental Research. The tasks of this project were to (1) develop, have approved, and adhere to a quality assurance project plan; (2) develop a technical support document for the impaired watershed; and (3) assist TCEQ with public participation. The purpose of this report is to provide technical documentation and supporting information for developing the bacteria TMDL for the impaired AU. This report contains:

- Information on historical data.
- Watershed properties and characteristics.
- Summary of historical bacteria data that confirm the Texas 303(d) listings of impairment due to concentrations of *E. coli*.

- Development of a load duration curve (LDC).
- Application of the LDC approach for developing the pollutant load allocation.

Whenever it was feasible, the data development and computations for developing the LDC and pollutant load allocation were performed in a manner to remain consistent with the previously completed *Addendum One: Six Additional Total Maximum Daily Loads for Indicator Bacteria in Watersheds Upstream of Lake Houston* (TCEQ, 2013), *Addendum Two: Two Total Maximum Daily Loads for Indicator Bacteria in Brushy Creek and Spring Branch* (TCEQ, 2019b), *Addendum Three: One Total Maximum Daily Load for Indicator Bacteria in Walnut Creek* (TCEQ, 2020b), and the original TMDL *Fifteen Total Maximum Daily Loads for Indicator Bacteria in Watersheds Upstream of Lake Houston* (TCEQ, 2011).

Section 2. Historical Data Review and Watershed Properties

2.1. Description of Study Area

The Caney Creek AU 1010_03 TMDL subwatershed drains 10.1 square miles (6,448 acres) and is located entirely within Montgomery County, east of Conroe, Texas (Figure 1). Caney Creek AU 1010_03 is a classified, perennial freshwater stream that is approximately 8.0 miles long and eventually feeds into Lake Houston.

The TMDL watershed for Caney Creek AU 1010_03 includes the contributing subwatersheds of upstream AUs 1010_01 and 1010_02, along with that of AU 1010_03, and is located within the Lake Houston watershed in the San Jacinto River Basin. The TMDL watershed covers portions of Montgomery and Walker counties and drains an area of 104.7 square miles (67,002 acres). Caney Creek (Segment 1010) is a tributary of the East Fork San Jacinto River (Segment 1003) and contains four AUs: 1010_01, 1010_02, 1010_03, and 1010_04 (Figure 1).

The TMDL subwatershed is predominantly rural, with one small city (Cut and Shoot) located partly in the TMDL subwatershed and two additional small cities (Willis and New Waverly) located partially within the TMDL watershed (Figure 1).

Caney Creek AU 1010_03 was fully supporting its designated contact recreation 1 use when previous TMDLs were developed for other water bodies within the Lake Houston watershed (Figure 2; TCEQ, 2011, 2013, 2019, and 2020b).

The 2020 Texas Integrated Report (TCEQ, 2020a) provides the following water body and AU description for Caney Creek:

- Caney Creek AU 1010_03 – From State Highway 105 to Farm-to-Market 2090

This TMDL takes a watershed approach to addressing the bacteria impairment. All TMDL allocations in this report were developed for the TMDL watershed (the AU 1010_03 subwatershed and its two upstream contributing subwatersheds). All wastewater treatment facilities (WWTFs) that discharge within the TMDL watershed are included within the scope of this report.

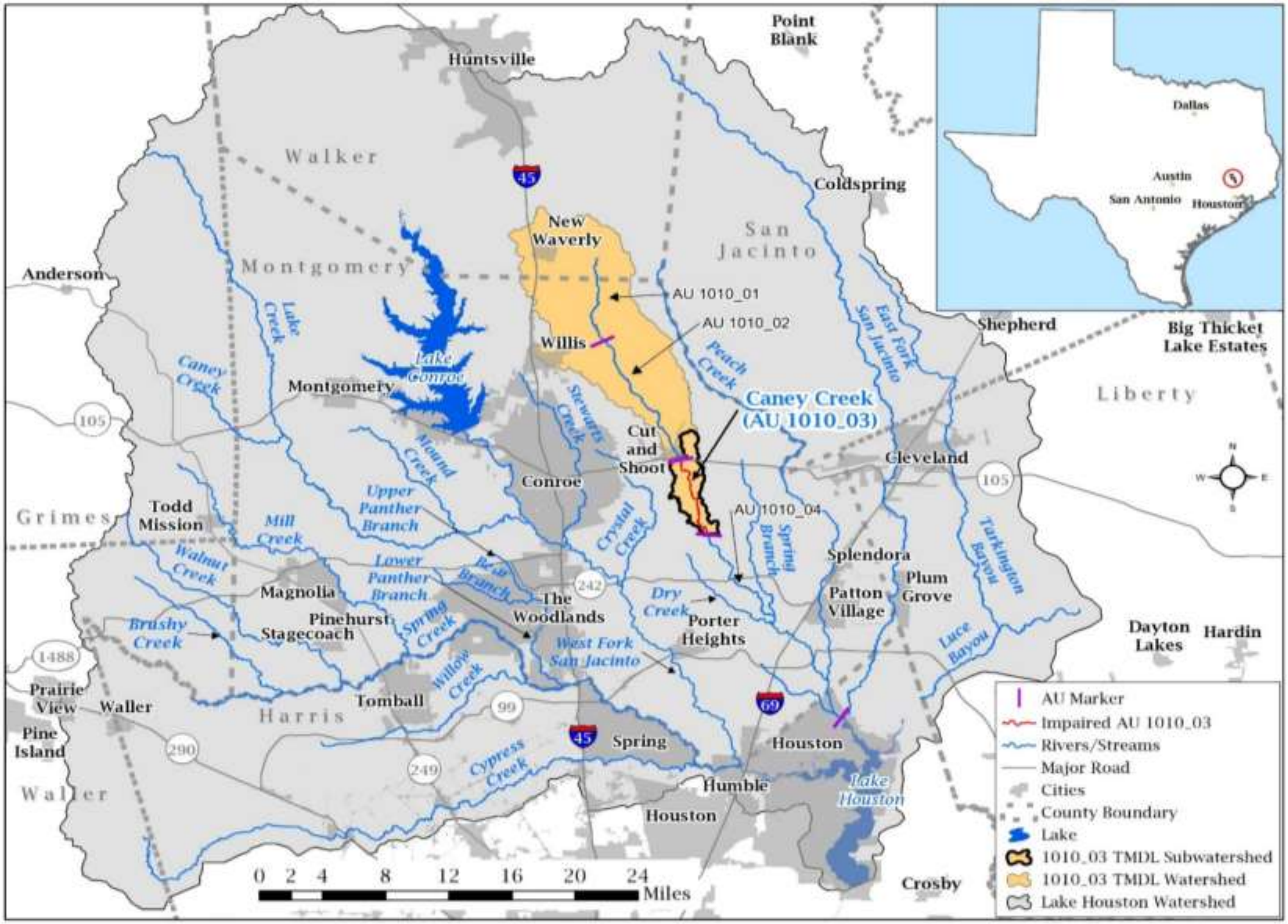

Figure 1. Overview map showing the TMDL subwatershed drainage area, the total contributing drainage area for the Caney Creek AU 1010_03 watershed, and the drainage areas for the existing TMDLs for the Lake Houston watershed

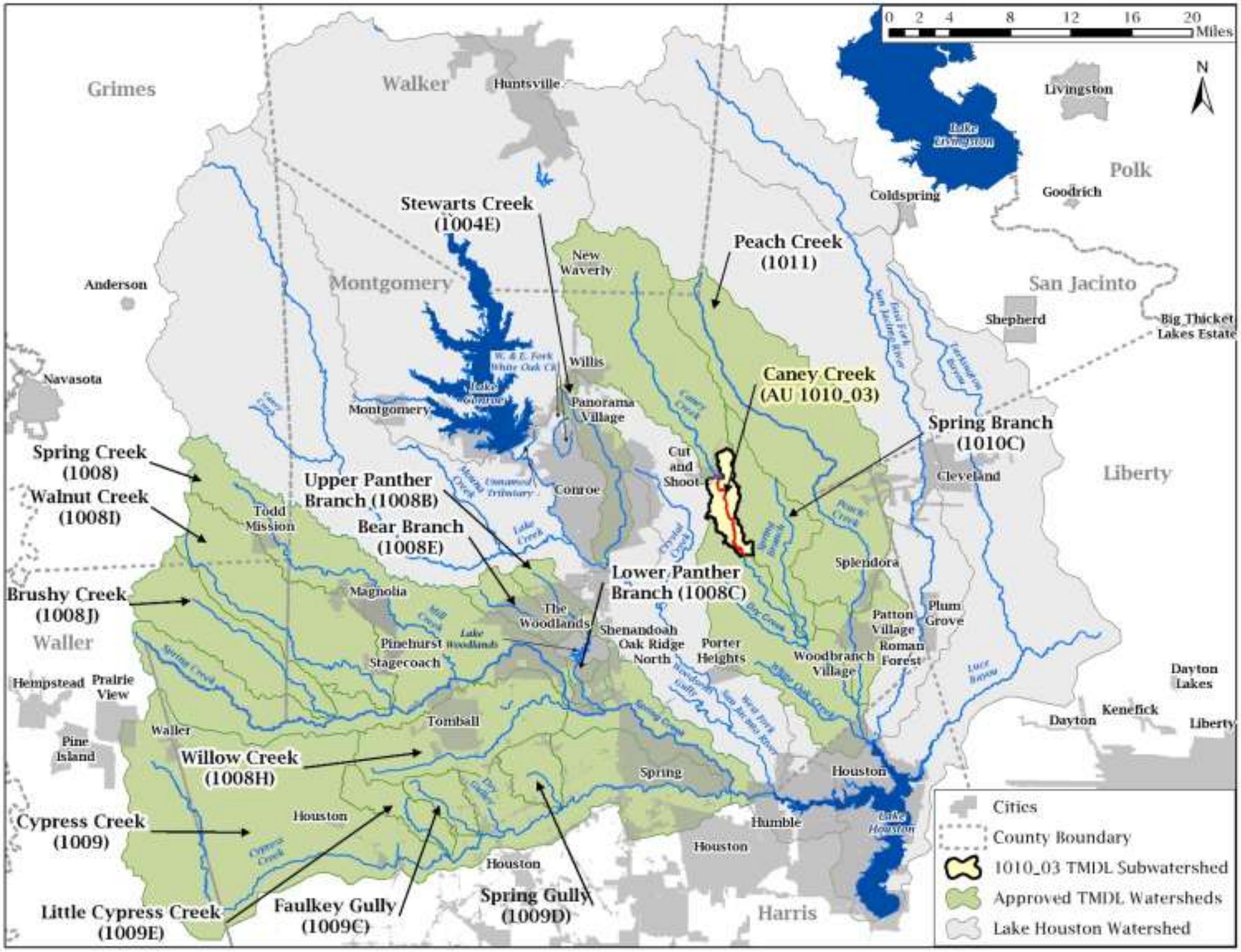

Figure 2. Map showing the previous TMDL watersheds and the Caney Creek AU 1010_03 TMDL subwatershed considered in this addendum

2.2. Review of Routine Monitoring Data

2.2.1. Analysis of Bacteria Data

Water quality has been monitored within the TMDL subwatershed at TCEQ surface water quality monitoring (SWQM) Station 11335 (Figure 3). *E. coli* data collected at Station 11335 on Caney Creek over the seven-year period from December 1, 2011, through November 30, 2018, were used in assessing attainment of the primary contact recreation 1 use, as reported in the 2020 Texas Integrated Report (TCEQ, 2020a). These data are summarized in Table 1. The 2020 assessment data for the TMDL subwatershed indicate continued non-support of the primary contact recreation 1 use because *E. coli* geometric mean concentrations exceed the criterion of 126 cfu/100 mL

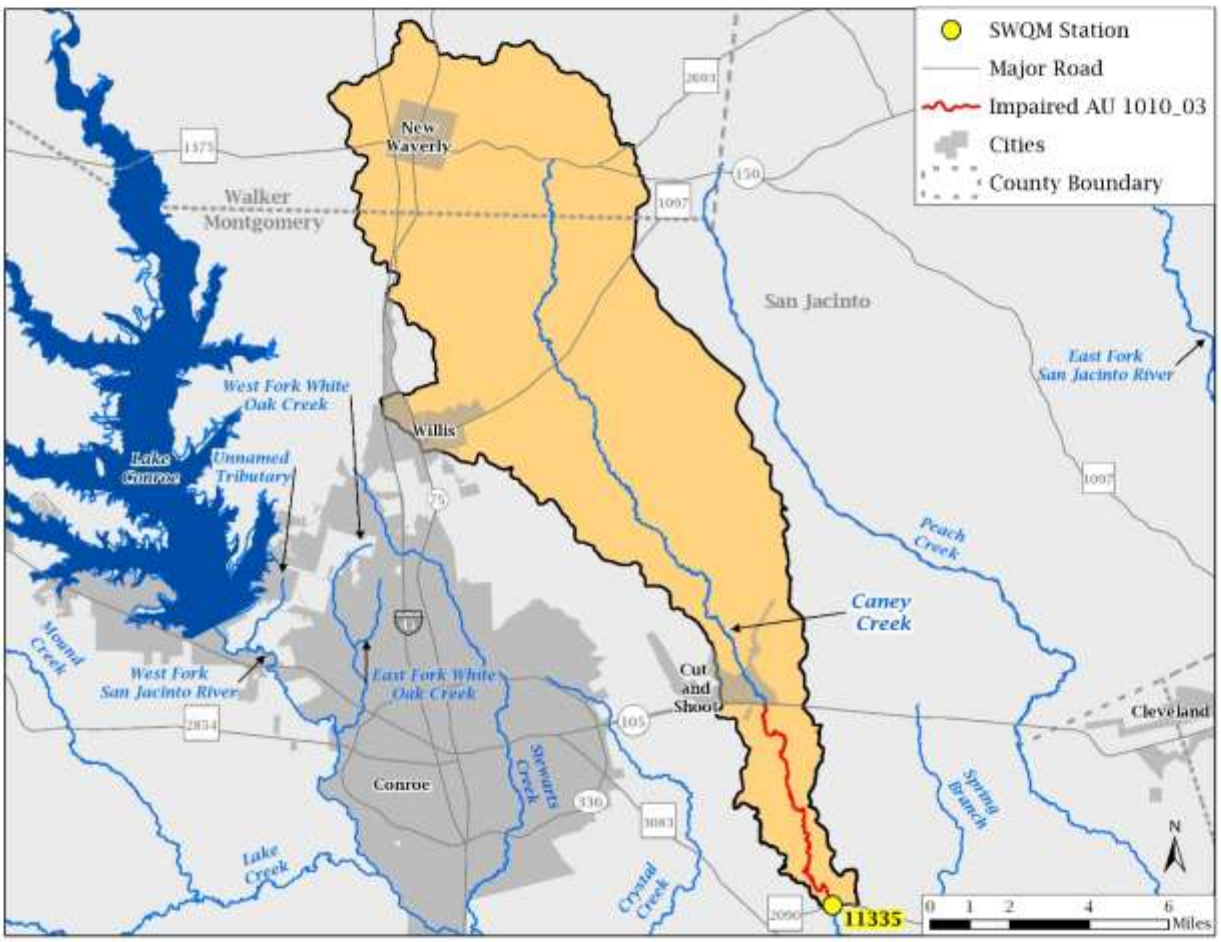

Figure 3. **Caney Creek TMDL watershed showing the TCEQ SWQM station used to assess the primary contact recreation 1 use**

Table 1. 2020 Texas Integrated Report summary for Caney Creek AU 1010_03

Watershed	AU	Parameter	TCEQ Station	No. of Samples	Data Date Range	Geometric Mean (cfu/100 mL)
Caney Creek	1010_03	E. coli	11335	29	2011–2018	221

2.3. Climate and Hydrology

The TMDL subwatershed is within the Upper Coast and East Texas climatic divisions, which are categorized as subtropical humid (Larkin & Bomar, 1983). The Gulf of Mexico is the principal source of moisture that drives precipitation in the region. For the 15-year period from 2006–2020, weather data were obtained from the National Oceanic and Atmospheric Administration (NOAA) National Centers for Environmental Information for the Conroe North Houston Regional Airport (NOAA, 2021). Data from this 15-year period indicate that the average high temperatures typically peak in August (95.1 ˚F). During winter, the average low temperature generally reaches a minimum of 38.3 ˚F in January (Figure 4). Annual rainfall averages 46.6 inches. The wettest month was May (5.3 inches), while February (2.7 inches) was the driest month, with rainfall occurring throughout the year.

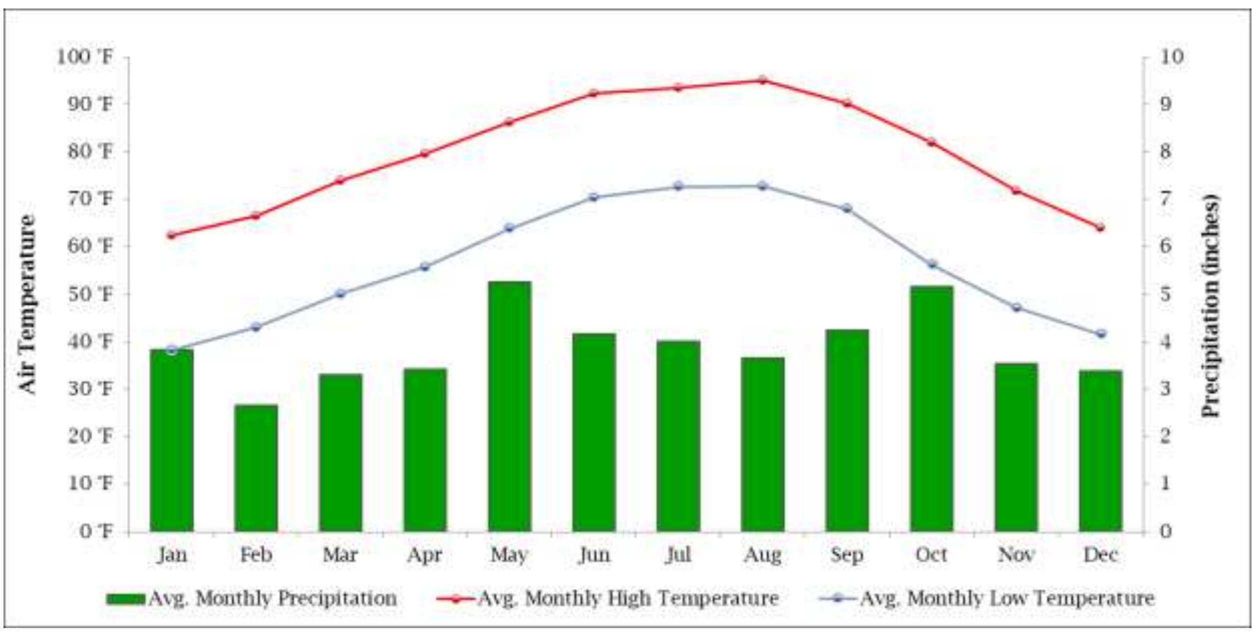

Figure 4. Average minimum and maximum air temperature and total precipitation by month from January 2006 through December 2020 for Conroe North Houston Regional Airport

2.4. Population and Population Projections

As depicted in Figure 1, the TMDL subwatershed is entirely within Montgomery County and includes a portion of one municipal boundary (Cut and Shoot). The TMDL watershed lies within Montgomery and Walker counties and includes portions of three municipal boundaries (Cut and Shoot, Willis, and New Waverly).

The rural nature of the watershed is evident given that the predominant population densities throughout the watershed are zero to two people per acre (Figure 5). According to the 2010 United States Census Bureau (USCB) data (USCB, 2010), the TMDL subwatershed has an estimated population of 2,629 people; the TMDL watershed has an estimated population of 18,037.

Population projections in Table 2 are estimated from the Texas Water Development Board (TWDB) 2021 Regional Water Plan Population and Water Demand Projection data ((TWDB, 2019a; TWDB, 2019b). According to the growth projections, population is expected to increase 310% in the TMDL subwatershed and 399% in the TMDL watershed by 2070. Additional information on this process can be found in Appendix A.

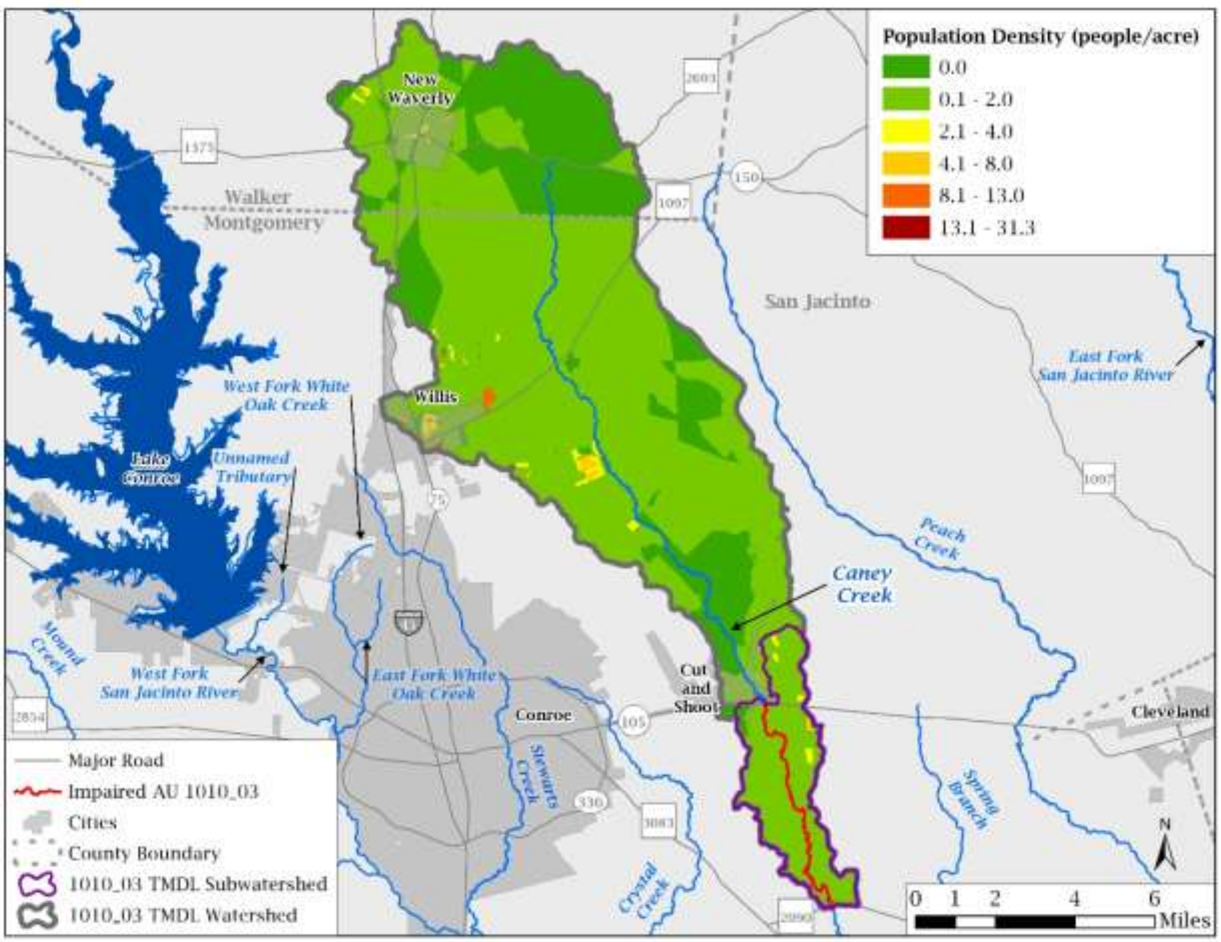

Figure 5. Population density based on the 2010 U.S. Census blocks

Table 2. 2010 population and population projections

Location	2010 U. S. Census	2070 Population Projection	Projected Population Increase (2010–2070)	Percentage Change
TMDL Subwatershed	2,629	10,781	8,152	310%
TMDL Watershed	18,037	89,993	71,956	399%

2.5. Land Cover

The land cover data presented in this report were obtained from the United States Geological Survey (USGS) 2016 National Land Cover Database (NLCD) (USGS, 2019). The land cover is represented by the following categories and definitions:

- Barren Land – Areas of bedrock, desert pavement, scarps, talus, slides, volcanic material, glacial debris, sand dunes, strip mines, gravel pits and other accumulations of earthen material. Generally, vegetation accounts for less than 15% of total cover.
- Developed, High Intensity – Highly developed areas where people reside or work in high numbers. Examples include apartment complexes, row houses, and commercial/industrial. Impervious surfaces account for 80% to 100% of the total cover.
- Developed, Low Intensity – Areas with a mixture of some constructed materials, but mostly vegetation in the form of lawn grasses. These areas most commonly include single-family housing units. Constructed surfaces account for 21% to 49% of total cover.
- Developed, Medium Intensity – Areas with a mixture of constructed materials and vegetation. Impervious surfaces account for 50% to 79% of the total cover. These areas most commonly include single-family housing units.
- Developed, Open Space – Areas with a mixture of some constructed materials, but mostly vegetation in the form of lawn grasses. Impervious surfaces account for less than 20% of total cover. These areas most commonly include large-lot single-family housing units, parks, golf courses, and vegetation planted in developed settings for recreation, erosion control, or aesthetic purposes.
- Deciduous Forest – Areas dominated by trees generally greater than five meters tall, and greater than 20% of total vegetation cover. More than 75% of the tree species shed foliage simultaneously in response to seasonal change.
- Evergreen Forest – Areas dominated by trees generally greater than five meters tall, and greater than 20% of total vegetation cover. More than 75% of the tree species maintain their leaves all year. Canopy is never without green foliage.

- Mixed Forest – Areas dominated by trees generally greater than five meters tall, and greater than 20% of total vegetation cover. Neither deciduous nor evergreen species are greater than 75% of total tree cover.
- Grassland/Herbaceous – Areas dominated by graminoid or herbaceous vegetation, generally greater than 80% of total vegetation. These areas are not subject to intensive management such as tilling, but can be utilized for grazing.
- Pasture/Hay – Areas of grasses, legumes, or grass-legume mixtures planted for livestock grazing or the production of seed or hay crops, typically on a perennial cycle. Pasture/hay vegetation accounts for greater than 20% of total vegetation.
- Shrub/Scrub – Areas dominated by shrubs less than five meters tall with shrub canopy typically greater than 20% of total vegetation. This class includes true shrubs, young trees in an early successional stage, or trees stunted from environmental conditions.
- Open Water – Areas of open water, generally with less than 25% cover of vegetation or soil.
- Emergent Herbaceous Wetlands – Areas where perennial herbaceous vegetation accounts for greater than 80% of vegetative cover and the soil or substrate is periodically saturated with or covered with water.
- Woody Wetlands – Areas where forest or shrubland vegetation accounts for greater than 20% of vegetative cover and the soil or substrate is periodically saturated with or covered with water.

The land cover data are provided for the TMDL subwatershed and the TMDL watershed in Figure 6. For the TMDL subwatershed, Mixed Forest (29.8%) and Evergreen Forest (13.9%) are the dominant land covers, comprising approximately 43.7% of the total land cover. For the entire TMDL watershed, Pasture/Hay (28.2%) and Evergreen Forest (28.1%) are the dominant land covers, comprising approximately 56.3% of the total land cover. Table 3 summarizes the land cover data for the TMDL watershed.

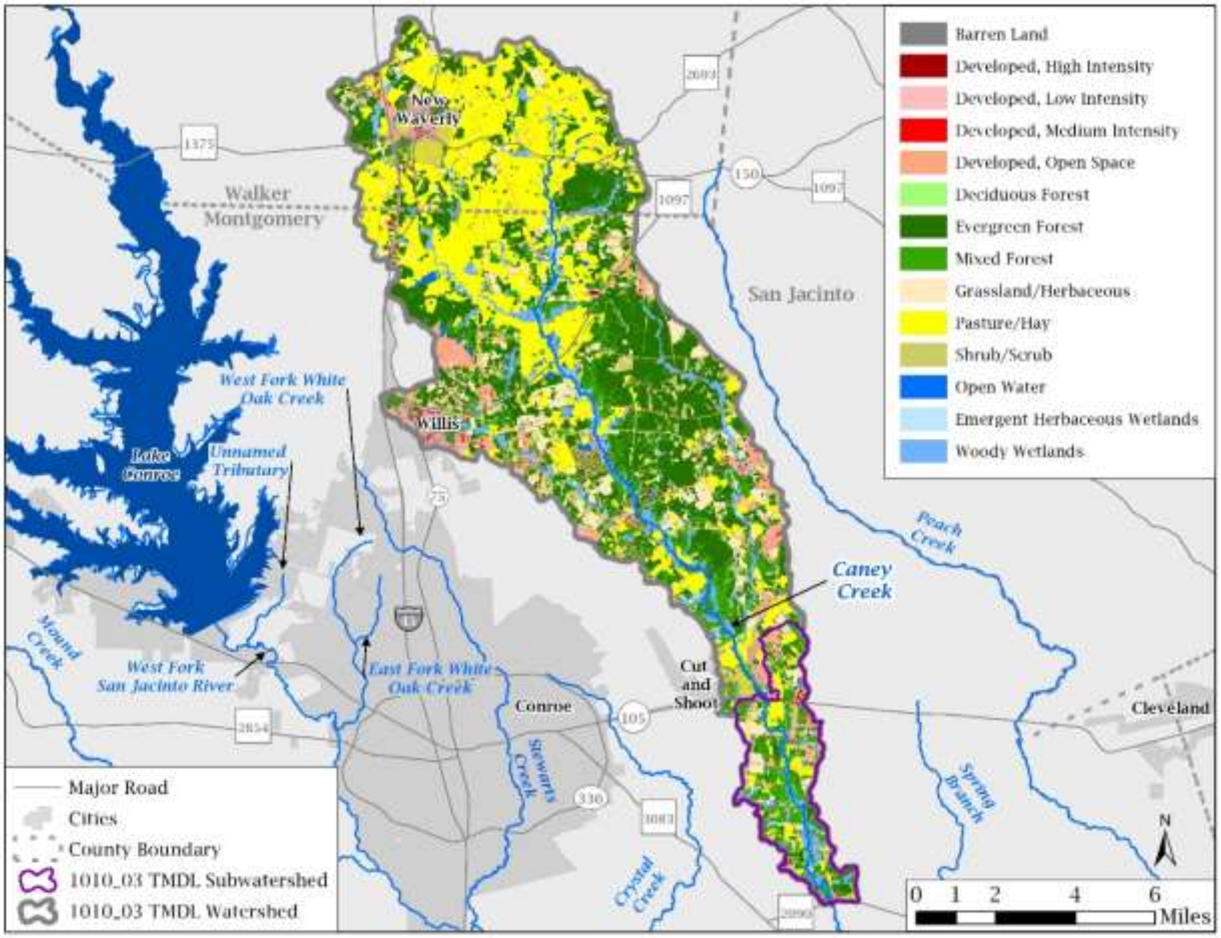

Figure 6. Land cover map of land use classifications

Table 3. Land cover classification percentages

Classification	TMDL Subwatershed Area (Acres)	TMDL Subwatershed Percentage of Total	TMDL Watershed Area (Acres)	TMDL Watershed Percentage of Total
Barren Land	24.6	0.4%	132.8	0.2%
Developed, High Intensity	9.4	0.1%	116.7	0.2%
Developed, Low Intensity	298.1	4.6%	2,374.9	3.5%
Developed, Medium Intensity	62.9	1.0%	427.9	0.6%
Developed, Open Space	573.5	8.9%	4,846.1	7.2%
Deciduous Forest	3.6	0.1%	66.8	0.1%
Evergreen Forest	898.8	13.9%	18,813.4	28.1%
Mixed Forest	1,922.9	29.8%	7,290.78	10.9%
Grassland/Herbaceous	679.9	10.5%	5,452.4	8.1%
Pasture/Hay	842.9	13.1%	18,888.5	28.2%

Classification	TMDL Subwatershed Area (Acres)	TMDL Subwatershed Percentage of Total	TMDL Watershed Area (Acres)	TMDL Watershed Percentage of Total
Shrub/Scrub	162.2	2.5%	2,855.1	4.3%
Open Water	23.1	0.4%	422.1	0.6%
Emergent Herbaceous Wetlands	55.4	0.9%	289.4	0.4%
Woody Wetlands	890.7	13.8%	5,025.2	7.5%
Total	6,448	100%	67,002	100%

2.6. Soils

Soils within the TMDL subwatershed as well as the TMDL watershed, categorized by their septic tank absorption field ratings (the method used in previous addenda in the Lake Houston watershed), are shown in Figure 7. These data were obtained through the United States Department of Agriculture (USDA) Natural Resources Conservation Service (NRCS) Gridded Soil Survey Geographic database (NRCS, 2019).

Soil properties and features such as saturated hydraulic conductivity, flooding, depth to bedrock, depth to cemented pan, ponding, rocks, fractured bedrock, subsidence, and excessive slope can affect septic tank effluent absorption, construction, maintenance, and public health (NRCS, 2019). The dominant soil condition within a septic drainage field can be used to identify soils that may prove problematic regarding septic system installation/performance and potentially lead to system failures such as effluent surfacing or downslope seepage.

Soils are rated based on the limiting factors (or conditions) affecting proper effluent drainage and filtering capacity. Soil conditions for septic tank drainage fields are expressed by the following rating terms and definitions (NRCS, 2019):

- Not Limited – Indicates that the soil has features that are very favorable for the specific use. Good performance and very low maintenance can be expected.
- Somewhat Limited – Indicates that the soil has one or more features that are moderately favorable for the specified use. The limitations can be overcome or minimized with special planning, design, and installation procedures. Fair performance and moderate maintenance can be expected.
- Very Limited – Indicates that the soil has one or more features that are unfavorable for the specified use. The limitations generally cannot be overcome without major soil reclamation, special design, or expensive installation procedures. Poor performance and high maintenance can be expected.
- Not Rated – Indicates insufficient data exists for soil limitation interpretation.

Most of the soils within the TMDL subwatershed are categorized as "Very Limited" with a fraction rated "Somewhat Limited" and the balance rated as "Not Rated" based on the dominant soil condition for septic drainage field installation and operation. The dominant soil category within the TMDL watershed is "Very Limited" with a fraction rated as "Not Rated" and the balance rated as "Somewhat Limited."

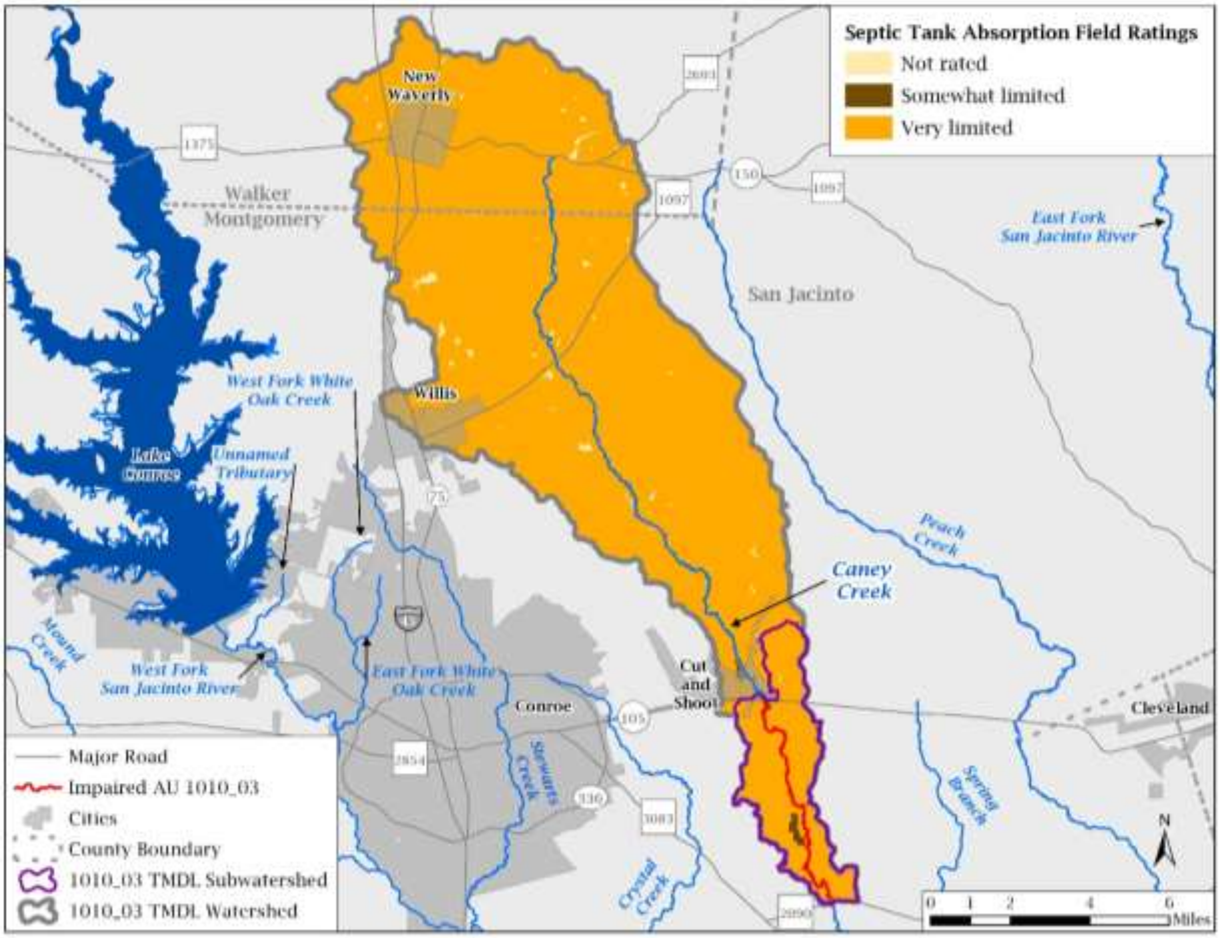

Figure 7. Septic tank absorption field limitation ratings

2.7. Potential Sources of Fecal Indicator Bacteria

Pollutants may come from several sources, both regulated and unregulated. Regulated pollutants, referred to as "point sources," come from a single definable point, such as a pipe, and are regulated by permit under the Texas Pollutant Discharge Elimination System (TPDES) program. WWTFs and regulated stormwater discharges from industries, construction, and the separate storm sewer systems of cities are considered point sources of pollution.

Unregulated sources are typically nonpoint source in origin, meaning the pollutants originate from multiple locations and rainfall runoff washes them into surface waters. Nonpoint sources are not regulated by permit.

Except for WWTFs, which receive individual wasteload allocations (WLAs) (see report Section 4.7.3., Wasteload Allocations), the regulated and unregulated sources in this section are presented to give a general account of the various sources of bacteria expected in the watershed. These are not meant to be used for allocating bacteria loads or interpreted as precise inventories and loadings.

2.7.1. Regulated Sources

Regulated sources are controlled by permit under the TPDES program. The regulated sources in the TMDL watershed include WWTF outfalls, stormwater discharges from regulated industrial and construction activities, and municipal separate storm sewer systems (MS4s).

2.7.1.1. Domestic Wastewater Treatment Facilities

As of August 23, 2021, there were five domestic WWTFs with TPDES permits within the TMDL subwatershed and 10 WWTFs with TPDES permits within the TMDL watershed (Table 4 and Figure 8). Recent discharge data are presented in Table 4 from Discharge Monitoring Report data (EPA, 2021).

2.7.1.2. TCEQ/TPDES General Wastewater Permits

Certain types of wastewater discharge must be covered by one of several TCEQ/TPDES general permits:

- TXG110000 – concrete production facilities
- TXG130000 – aquaculture production facilities
- TXG340000 – petroleum bulk stations and terminals
- TXG640000 – conventional water treatment plants
- TXG670000 – hydrostatic test water
- TXG830000 – water contaminated by petroleum fuel or petroleum substances
- TXG870000 – pesticides (application only)
- TXG920000 – concentrated animal feeding operations
- WQG100000 – wastewater evaporation
- WQG200000 – livestock manure compost operations (irrigation only)

Table 4. Permitted domestic WWTFs

Watershed	Permittee	Facility	TPDES No.	NPDES[a] No.	Daily Average Flow – Permitted Discharge (MGD)[b]	Daily Average Flow – Recent Discharge (MGD)[c]
TMDL Subwatershed	Conroe Independent School District (ISD)	Stephen F. Austin WWTF	WQ0012204001	TX0083216	0.02	0.004
TMDL Subwatershed	C & R Water Supply Inc.	Emerson Estates WWTF	WQ0014285001	TX0124281	0.30	0.154
TMDL Subwatershed	Crystal Springs Water Co., Inc.	Forest Trace WWTF	WQ0015261001	TX0135453	0.325	0.041
TMDL Subwatershed	Crockett Martin Corp.	Crockett Martin Estates MHC WWTF	WQ0015689001	TX0138568	0.025	-------[d]
TMDL Subwatershed	Crystal Springs Water Co., Inc.	White Rock WWTF	WQ0016005001	TX0141399	0.75	-------[d]
TMDL Watershed	City of New Waverly	New Waverly WWTF No. 1	WQ0011020001	TX0056685	0.088	0.042
TMDL Watershed	City of New Waverly	New Waverly WWTF No. 2	WQ0011020002	TX0087831	0.10	0.060
TMDL Watershed	Texas National Municipal Utility District (MUD)	Texas National MUD WWTF	WQ0011715001	TX0068659	0.225	0.054
TMDL Watershed	Quadvest, L.P.	Caddo Village WWTF	WQ0012670001	TX0092517	0.175	0.076
TMDL Watershed	Texas Campgrounds Club, Inc.	Texas Campgrounds Club WWTF	WQ0015984001	TX0141224	0.04	-------[d]

[a] NPDES = National Pollutant Discharge Elimination System

[b] MGD = million gallons per day

[c] Reflects discharges available from May 1, 2016 – April 30, 2021

[d] No available records.

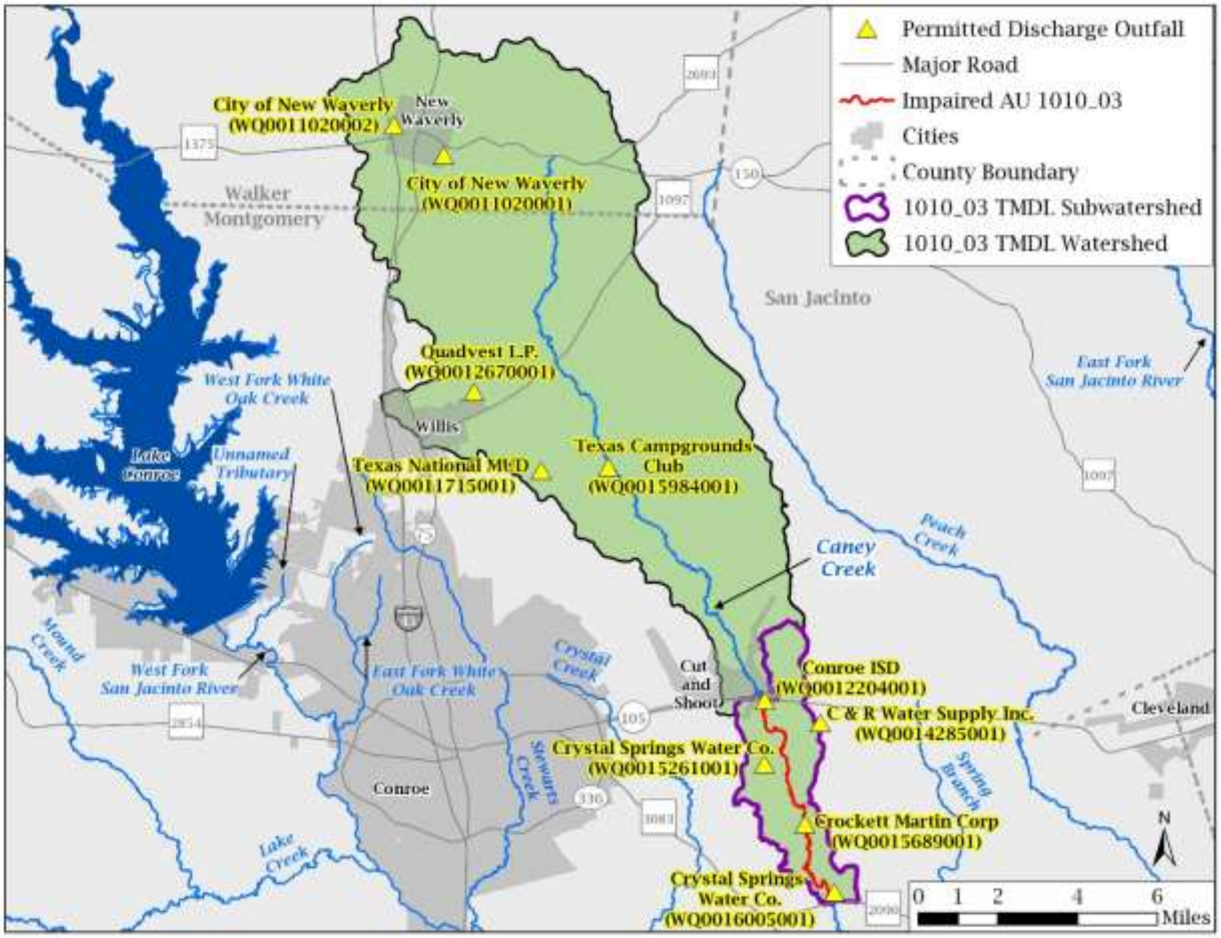

Figure 8. WWTFs in the TMDL watershed

A review of active general permits (TCEQ, 2021a) in the TMDL subwatershed as of June 2, 2021, found one general permit authorization for a concrete production facility and one general permit authorization for pesticide application. The concrete production facility and pesticide management area do not have bacteria reporting requirements or limits in their permit authorizations. Pesticide application in the pesticide management area was assumed to contain inconsequential amounts of indicator bacteria; therefore, it was unnecessary to allocate bacteria loads to this area. No other active wastewater general permit authorizations were found.

2.7.1.3. TPDES-Regulated Stormwater

When evaluating stormwater for a TMDL allocation, a distinction must be made between stormwater originating from an area under a TPDES-regulated discharge permit and stormwater originating from areas not under a TPDES-regulated discharge permit. Stormwater discharges fall into two categories:

1. Stormwater subject to regulation, which is any stormwater originating from TPDES-regulated MS4 entities, stormwater discharges associated with regulated industrial facilities, and construction activities.

2. Stormwater runoff not subject to regulation.

TPDES MS4 Phase I and II rules require municipalities and certain other entities in urbanized areas to obtain permit coverage for their stormwater systems. A regulated MS4 is a publicly owned system of conveyances and includes ditches, curbs, gutters, and storm sewers that do not connect to a wastewater collection system or treatment facility. Phase I permits are individual permits for large and medium-sized communities with populations of 100,000 or more based on the 1990 U.S. Census, while the Phase II General Permit regulates other MS4s within a USCB defined urbanized area.

The purpose of an MS4 permit is to reduce discharges of pollutants in stormwater to the "maximum extent practicable" by developing and implementing a stormwater management program (SWMP). The SWMP describes the stormwater control practices that the regulated entity will implement, consistent with permit requirements, to minimize the discharge of pollutants. MS4 permits require that SWMPs specify the best management practices to meet several minimum control measures (MCMs) that, when implemented in concert, are expected to result in significant reductions of pollutants discharged into receiving water bodies. Phase II MS4 MCMs include all of the following:

- Public education, outreach, and involvement.
- Illicit discharge detection and elimination.
- Construction site stormwater runoff control.
- Post-construction stormwater management in new development and redevelopment.
- Pollution prevention and good housekeeping for municipal operations.
- Industrial stormwater sources.

Phase I MS4 individual permits have their own set of MCMs that are similar to the Phase II MCMs, but Phase I permits have additional requirements to perform water quality monitoring and implement a floatables program. The Phase I MCMs include all of these activities:

- MS4 maintenance activities.
- Post-construction stormwater control measures.
- Detection and elimination of illicit discharges.
- Pollution prevention and good housekeeping for municipal operations.
- Limiting pollutants in industrial and high-risk stormwater runoff.
- Limiting pollutants in stormwater runoff from construction sites.
- Public education, outreach, involvement, and participation.
- Monitoring, evaluating, and reporting.

Discharges of stormwater from a Phase II MS4 area, regulated industrial facility, construction area, or other facility involved in certain activities must be covered under the following TCEQ/TPDES general permits:

- TXR040000 – Phase II MS4 General Permit for small MS4s located in urbanized areas
- TXR050000 – Multi-Sector General Permit (MSGP) for industrial facilities
- TXR150000 – Construction General Permit for construction activities disturbing more than one acre or are part of a common plan of development disturbing more than one acre

There is currently one combined Phase I/II permit authorization within the urbanized area of the TMDL subwatershed and the TMDL watershed (Table 5). A review of active MS4 general permit coverage (TCEQ, 2021a) revealed two active Phase II MS4 permit authorizations in the TMDL watershed, one of which is located in the TMDL subwatershed as of September 14, 2021 (Table 5 and Figure 9).

A review of other active stormwater general permit coverage (TCEQ, 2021a) in the Caney Creek TMDL subwatershed as of September 14, 2021, found one active MSGP authorization and four construction authorizations within the TMDL subwatershed. Additionally, the review found two active MSGP authorizations and 17 construction authorizations within the TMDL watershed. See Section 4.7.3. for more detailed information.

Table 5. TPDES MS4 permits

Watershed	Entity	TPDES Permit	NPDES Permit	Permit Type
TMDL	Texas Department of Transportation	WQ0005011000	TXS002101	Combined Phase I/II
TMDL	Montgomery County	Phase II General Permit (TXR040000)	TXR040348	Phase II
TMDL	City of Willis	Phase II General Permit (TXR040000)	TXR040538	Phase II

2.7.1.4. Sanitary Sewer Overflows

Sanitary sewer overflows (SSOs) are unauthorized discharges that must be addressed by the responsible party, either the TPDES permittee or the owner of the collection system that is connected to a permitted system. These overflows in dry weather most often result from blockages in the sewer collection pipes caused by tree roots, grease, and other debris. Inflow and infiltration (I&I) are typical causes of SSOs under conditions of high flow in the WWTF system. Blockages in the line may exacerbate the I&I problem. Other causes, such as a collapsed sewer line, may occur under any condition.

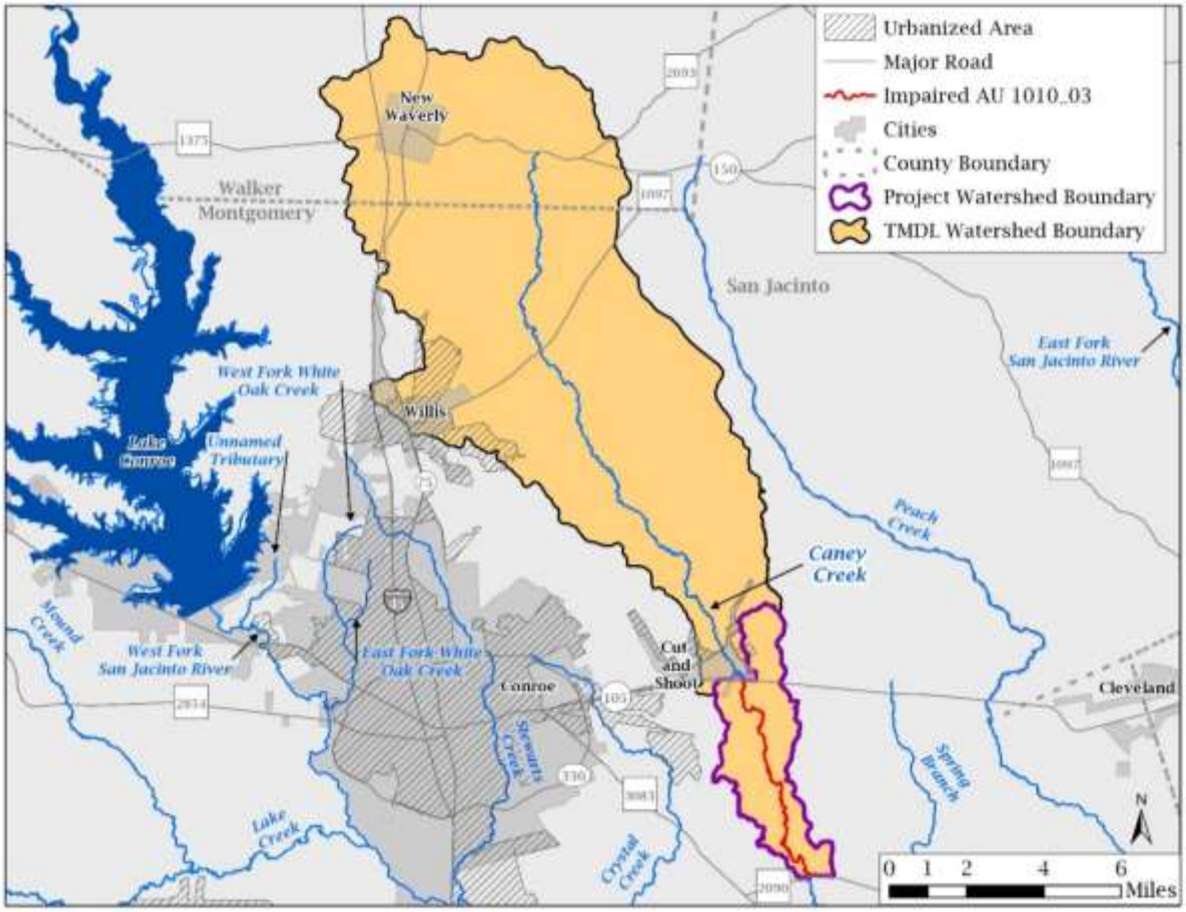

Figure 9. Regulated stormwater areas based on Phase I and Phase II MS4 permits as defined by the urbanized area

The TCEQ Region 12 Office maintains a database of SSO data reported by municipalities. These SSO data typically contain estimates of the total gallons spilled, responsible entity, and a general location of the spill. A summary of SSO incidents that occurred during a four-year period from 2016–2019 in the project counties (Montgomery and Waller) was obtained from the TCEQ Office of Compliance and Enforcement in Austin. The summary data indicated two SSO incidents were reported for locations within the TMDL subwatershed and 15 SSO incidents were reported for locations in the TMDL watershed. The causes of the SSOs include equipment failure, power outage, and act of God. Table 6 contains a summary of the reported SSO incidents.

Table 6. Summary of SSO incidents

Watershed	Number of Incidents	Total Volume (gallons)	Min Volume (gallons)	Max Volume (gallons)	Avg Volume (gallons)
TMDL Subwatershed	2	500	1	500	250
TMDL Watershed	15	36,327	1	24,000	2,422

2.7.1.5. Dry Weather Discharges/Illicit Discharges

Pollutant loads can enter water bodies from MS4 outfalls that carry authorized sources as well as illicit discharges under both dry- and wet-weather conditions. The term "illicit discharge" is defined in TPDES General Permit No. TXR040000 for Phase II MS4s as "Any discharge to a municipal separate storm sewer system that is not entirely composed of stormwater, except discharges pursuant to this general permit or a separate authorization and discharges resulting from emergency firefighting activities." Illicit discharges can be categorized as either direct or indirect contributions. Examples of illicit discharges identified in the *Illicit Discharge Detection and Elimination Manual: A Handbook for Municipalities* (NEIWPCC, 2003) include:

Direct illicit discharges

- Sanitary wastewater piping that is directly connected from a home to the storm sewer.
- Materials that have been dumped illegally into a storm drain catch basin.
- A shop floor drain that is connected to the storm sewer.
- A cross-connection between the municipal sewer and storm sewer systems.

Indirect illicit discharges

- An old and damaged sanitary sewer line that is leaking fluids into a cracked storm sewer line.
- A failing septic system that is leaking into a cracked storm sewer line or causing surface discharge into the storm sewer.

2.7.2. Unregulated Sources

Unregulated sources of bacteria are generally nonpoint. Nonpoint source loading enters the impaired water body through distributed, nonspecific locations, which may include urban runoff not covered by a permit. Potential sources, detailed below, include wildlife, feral hogs, various agricultural activities, agricultural animals, land application fields, urban runoff not covered by a permit, failing on-site sewage facilities (OSSFs), and domestic pets.

2.7.2.1. Wildlife and Unmanaged Animal Contributions

Fecal bacteria are common inhabitants of the intestines of all warm-blooded animals, including feral hogs and wildlife such as mammals and birds. In developing bacteria

TMDLs, it is important to identify by watershed the potential for bacteria contributions from wildlife and feral hogs. Wildlife and feral hogs are naturally attracted to riparian corridors of water bodies. With direct access to the stream channel, the direct deposition of wildlife and feral hog waste can be a concentrated source of bacteria loading to a water body. Fecal bacteria from wildlife and feral hogs are also deposited onto land surfaces, where they may be washed into nearby streams by rainfall runoff.

Unfortunately, quantitative estimates of wildlife are rare, inexact, and often limited to discrete taxa groups or geographical areas of interest so that even county-wide approximations of wildlife numbers are difficult or impossible to acquire. Bird diversity is high in the counties where the TMDL watershed is located (eBird, 2021), but population sizes for individual species are not known. However, population estimates for feral hogs and deer are readily available for the TMDL watershed.

For feral hogs, a study by Timmons et al. (2012) estimated a range of feral hog densities within suitable habitat in Texas (8.9 to 16.4 hogs/square mile). The average hog density (12.65 hogs/square mile) was multiplied by the hog-habitat area (8.53 square miles) in the TMDL subwatershed and the hog-habitat area (91.69 square miles) in the TMDL watershed. Habitat deemed suitable for hogs followed as closely as possible to the land cover selections of the study and include from the 2016 NLCD land cover: Forest, Wetlands, Pasture/Hay, Shrub/Scrub, and Grassland/Herbaceous. Using this methodology, there are an estimated 108 feral hogs in the TMDL subwatershed and 1,160 feral hogs in the TMDL watershed.

For deer, the Texas Parks and Wildlife Department (TPWD) published data showing deer population-density estimates by Deer Management Unit (DMU) and Ecoregion in the state (TPWD, 2021). The TMDL subwatershed and the TMDL watershed is located within portions of DMU 14 and the DMU Urban Houston for which there is no deer density data. Due to the lack of deer density data for DMU Urban Houston, density data from DMU 14 was used to estimate deer populations for both watersheds. For the 2020 TPWD survey year, the estimated deer population density for DMU 14 was 25.03 deer/1,000 acres and applies to all habitat types within the DMU area. Applying this value to the TMDL watershed returns an estimated 161 deer within the TMDL subwatershed and 1,677 deer within the TMDL watershed.

The *E. coli* contribution from feral hogs and wildlife could not be determined based on existing information.

2.7.2.2. Unregulated Agricultural Activities and Domesticated Animals

Several agricultural activities that do not require permits can be potential sources of fecal bacteria loading. The number of livestock within the TMDL watershed was estimated from county-level data obtained from the 2017 Census of Agriculture (USDA NASS, 2019). The county-level data for Montgomery and Walker counties were refined to better reflect actual numbers within the TMDL subwatershed and the TMDL watershed. The refinement was performed by dividing the total area of suitable grazing land in the watershed within each county by the total area of suitable grazing land in each county. This ratio was then applied to the county-level livestock data (Table 7). The livestock numbers in Table 7 are provided to demonstrate that livestock are a potential source of bacteria in the TMDL watershed. These livestock numbers are not used to develop an allocation of allowable bacteria loading to livestock.

Table 7. Estimated distributed domesticated animal populations

Watershed	Cattle and Calves	Hogs and Pigs	Poultry	Goats and Sheep	Horses
TMDL Subwatershed	182	15	126	34	34
TMDL Watershed	3,352	152	3,758	422	437

Fecal bacteria from dogs and cats are transported to water bodies by runoff in both urban and rural areas and can be a potential source of bacteria loading. Table 8 summarizes the estimated number of dogs and cats within the TMDL watershed. Pet population estimates were calculated as the estimated number of dogs (0.614) and cats (0.457) per household according to data from the American Veterinary Medical Association 2017–2018 U.S. Pet Statistics (AVMA, 2018). The number of households in the TMDL watershed were estimated using 2010 Census data (USCB, 2010). The actual contribution and significance of bacteria loads from pets reaching the water bodies is unknown.

Table 8. Estimated distribution of dog and cat populations

Watershed	Households	Dogs	Cats
TMDL Subwatershed	825	507	377
TMDL Watershed	6,214	3,815	2,840

2.7.2.3. On-site Sewage Facilities

Private residential OSSFs, commonly referred to as septic systems, consist of various designs based on physical conditions of the local soils. Typical designs consist of 1) one or more septic tanks and a drainage or distribution field (anaerobic system) and 2) aerobic systems that have an aerated holding tank and often an above ground sprinkler system for distributing the liquid. In simplest terms, household waste flows into the septic tank or aerated tank, where solids settle out. The liquid portion of the water flows to the distribution system that may consist of buried perforated pipes or an above ground sprinkler system.

Several pathways of the liquid waste in OSSFs afford opportunities for bacteria to enter ground and surface waters if the systems are not properly operating. Properly designed and operated, however, OSSFs would be expected to contribute virtually no fecal bacteria to surface waters. For example, it has been reported that less than 0.01% of fecal coliforms originating in household wastes move further than 6.5 feet down gradient of the drain field of a septic system (Weiskel et al., 1996). Reed, Stowe, and Yanke LLC (2001) provide information on estimated failure rates of OSSFs for different regions of Texas. Caney Creek is located within the east-central Texas Region V, which has a reported failure rate of 19%, providing insight into expected failure rates for the area.

Estimates of the number of OSSFs in the TMDL subwatershed and the TMDL watershed were determined using data supplied by the Houston-Galveston Area Council for Montgomery and Walker Counties. Data from these sources indicate that there are 196 OSSFs located within the TMDL subwatershed and 1,981 within the TMDL watershed (Figure 10).

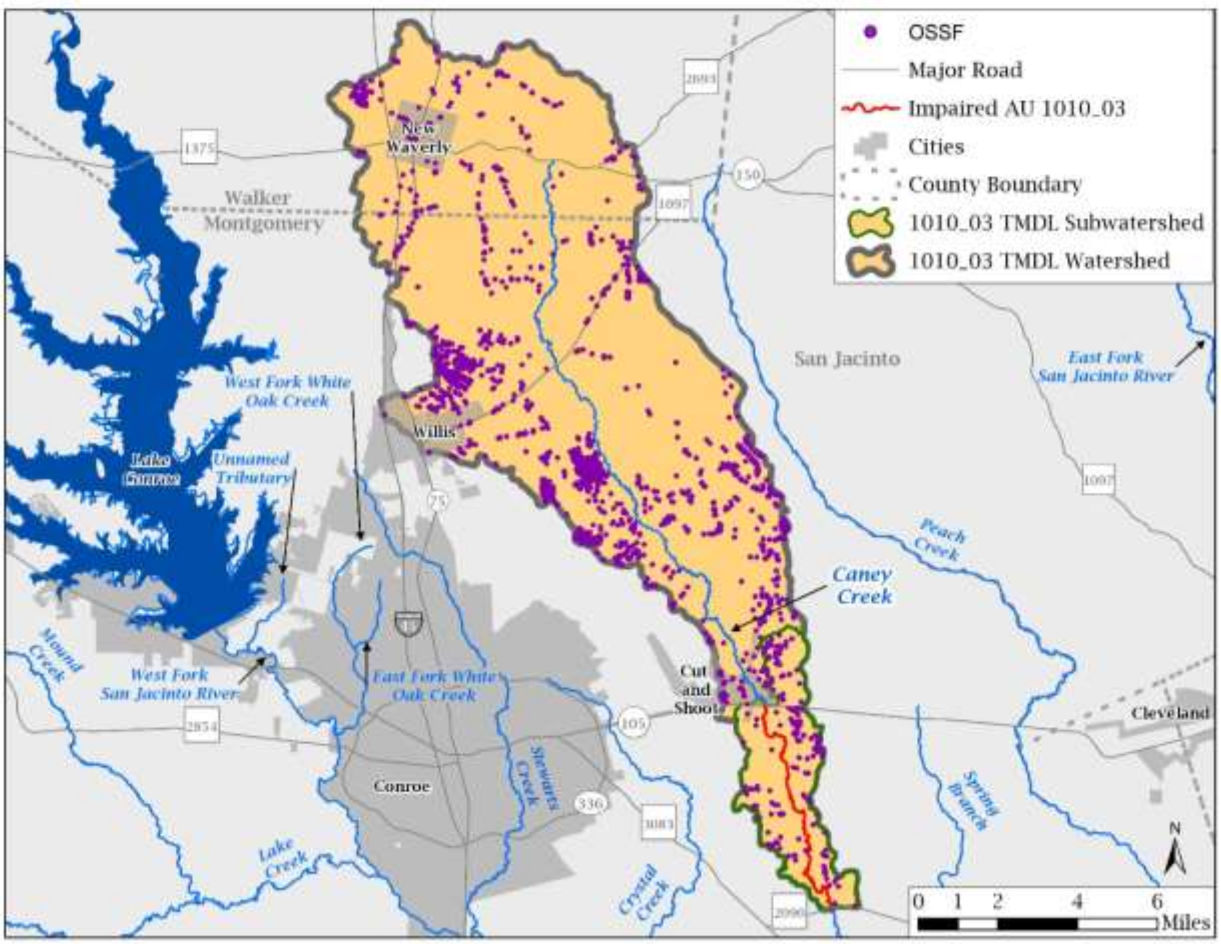

Figure 10. OSSFs in the TMDL watershed

2.7.2.4. Bacteria Survival and Die-off

Bacteria are living organisms that survive and die. Certain enteric bacteria can survive and replicate in organic materials if appropriate conditions prevail (e.g., warm temperature). Fecal organisms from improperly treated effluent can survive and replicate during their transport in pipe networks, and they can survive and replicate in organic-rich materials such as improperly treated compost and sewage sludge (or biosolids). While the die-off of indicator bacteria has been demonstrated in natural water systems due to the presence of sunlight and predators, the potential for their re-growth is less well understood. Both replication and die-off are instream processes and are not considered in the bacteria source loading estimates in the TMDL watershed.

Section 3. Bacteria Tool Development

This section describes the rationale of the bacteria tool selection for TMDL development and details the procedures and results of LDC development.

3.1. Tool Selection

For consistency between the Caney Creek AU 1010_03 TMDL and the previously completed TMDLs in the Lake Houston watershed, the pollutant load allocation activities for Caney Creek AU 1010_03 used the LDC method. The LDC method has been previously used on TCEQ-adopted and EPA-approved TMDLs for the TMDL *Addendum One: Six Additional Total Maximum Daily Loads for Indicator Bacteria in Watersheds Upstream of Lake Houston* (TCEQ, 2013), *Addendum Two: Two Total Maximum Daily Loads for Indicator Bacteria in Brushy Creek and Spring* Branch (TCEQ, 2019b), *Addendum Three: One Total Maximum Daily Load for Indicator Bacteria in Walnut Creek* (TCEQ, 2020b), and *Fifteen Total Maximum Daily Loads for Indicator Bacteria in Watersheds Upstream of Lake Houston* (TCEQ, 2011).

The LDC method allows for estimation of existing and allowable loads by utilizing the cumulative frequency distribution of streamflow and measured pollutant concentration data (Cleland, 2003). In addition to estimating stream loads, the LDC method allows for the determination of the hydrologic conditions under which impairments are typically occurring. This information can be used to identify broad categories of sources (point and nonpoint) that may be contributing to the impairment. The LDC method has found relatively broad acceptance among the regulatory community, primarily due to the simplicity of the approach and ease of application. The regulatory community recognizes the frequent information limitations often associated with bacteria TMDLs that constrain the use of more powerful mechanistic models. Further, the bacteria task force appointed by TCEQ and the Texas State Soil and Water Conservation Board supports application of the LDC method within their three-tiered approach to TMDL development (Jones et al., 2009). The LDC method provides a means to estimate the difference in bacteria loads and relevant criterion and can give indications of broad sources of the bacteria.

3.2. Data Resources

Successful application of the LDC method requires two basic types of data: continuous daily streamflow data and historical bacteria data for the relevant indicator bacteria, which in this case is *E. coli*.

Hydrologic data in the form of daily streamflow records were available for the Caney Creek AU 1010_03 watershed. Streamflow records for the Caney Creek AU 1010_03 watershed are collected and made readily available by the USGS; (USGS, 2021), which operates the streamflow gauge (Figure 11, Table 9). USGS streamflow gauge 08070500 is located along the mainstem of Caney Creek and is collocated with Station 11335 at the outlet of the TMDL subwatershed; therefore, the same precipitation events would likely impact each watershed. The determination was made to modify the streamflow records for Caney Creek 08070500 by using a drainage-area ratio (DAR) approach. This approach is explained in more detail in Section 3.3.3. The modified streamflow records from 08070500 serve as the primary source for streamflow records in this document.

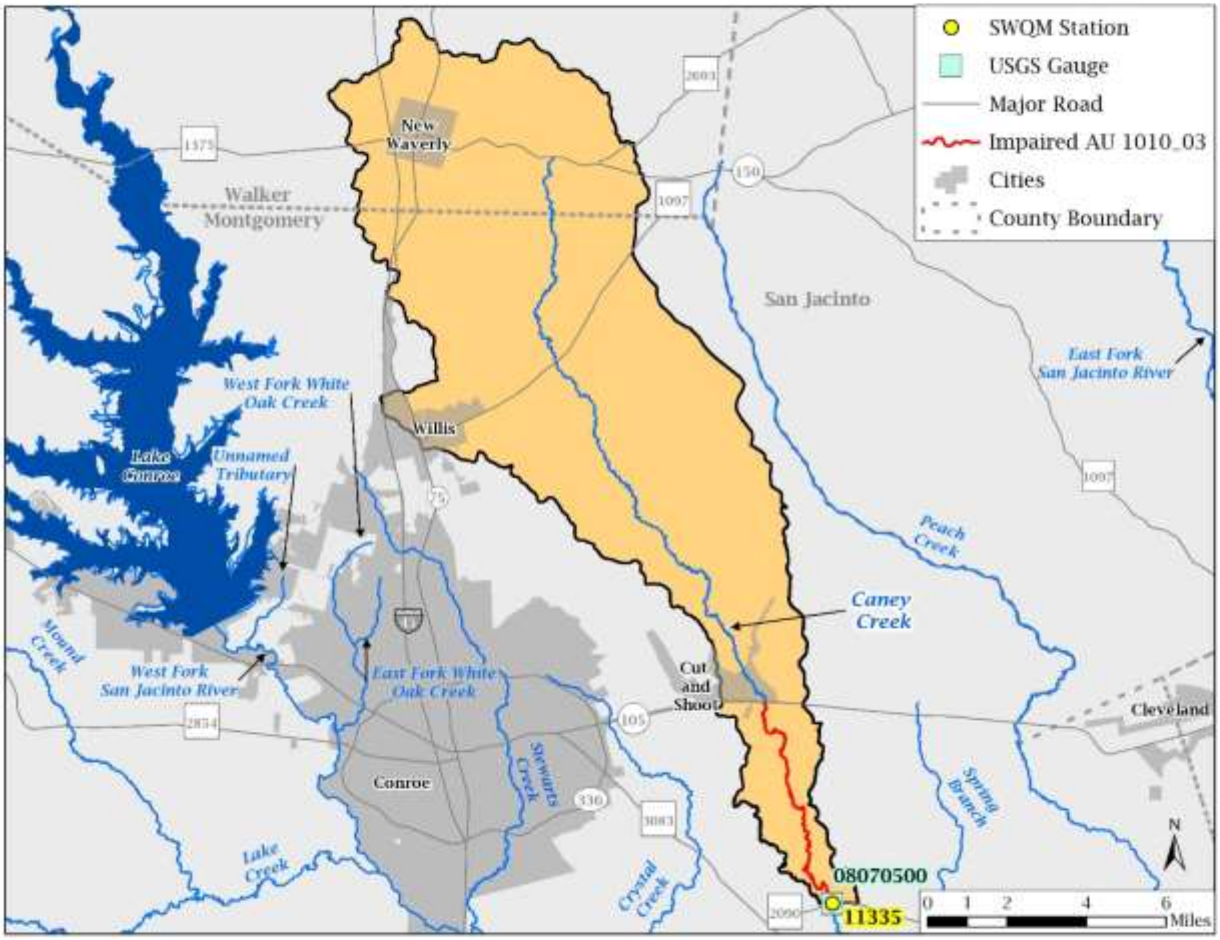

Figure 11. TMDL watershed showing USGS Station 08070500 and SWQM Station 11335

Table 9. Caney Creek USGS streamflow gauge information

Gauge No.	Site Description	Drainage Area (acres)	Daily Streamflow Record (beginning & end date)
08070500	Caney Creek near Splendora, TX	67,002	Jan. 1944 – present

Ambient *E. coli* data were available through the TCEQ Surface Water Quality Monitoring Information System for TCEQ Station 11335 and consisted of 34 *E. coli* sample results with a geometric mean of 225 cfu/100 mL collected over a period from February 2012 to February 2020.

3.3. Methodology for Flow Duration and Load Duration Curve Development

To develop the flow duration curve (FDC) and LDC, the previously discussed data resources were used in the following series of sequential steps.

- Step 1: Determine the hydrologic period of record to be used in developing the FDC.
- Step 2: Determine the stream location for which FDC and LDC development is desired.
- Step 3: Develop DAR parameter estimates.
- Step 4: Develop daily streamflow records at the desired stream location using the daily gauged streamflow records and DAR.
- Step 5: Develop an FDC at the desired stream location, segmented into discrete flow regimes.
- Step 6 Develop the allowable bacteria LDC at the same stream location based on the relevant criteria and the data from the FDC.
- Step 7: Superpose historical bacteria data on each allowable bacteria LDC.

See additional information explaining the LDC method in Cleland (2003) and EPA (2007).

3.3.1. Step 1: Determine Hydrologic Period

A 76-year daily hydrologic (streamflow) record was available for USGS gauge 08070500 located on Caney Creek (Table 10, Figure 11). Optimally, the period of record to develop FDCs should include as much data as possible to capture streamflow and hydrologic variability from high to low precipitation years, be representative of recent conditions, and overlap with the *E. coli* data period of record. Therefore, a 10-year record of daily streamflow, from January 2011 through December 2020, was selected to develop the FDC at the sampling station location, this period is within the range of the collection dates of available *E. coli* data. A 10-year period is of sufficient duration to contain a reasonable variation from dry months and years to wet months and years and at the same time is short enough in duration to contain a hydrology that is responding to recent and current conditions in the watershed. A 10-year hydrologic period was also used in the previously completed TMDL *Addendum One: Six Additional Total Maximum Daily Loads for Indicator Bacteria in Watersheds Upstream of Lake Houston* (TCEQ, 2013), *Addendum Two: Two Total Maximum Daily Loads for Indicator Bacteria in Brushy Creek and Spring Branch* (TCEQ, 2019b), *Addendum Three: One Total Maximum Daily Load for Indicator Bacteria in Walnut Creek* (TCEQ, 2020b), and *Fifteen Total Maximum Daily Loads for Indicator Bacteria in Watersheds Upstream of Lake Houston* (TCEQ, 2011) which maintains consistency of the Caney Creek AU 1010_03 TMDL with the previous TMDLs.

3.3.2. Step 2: Determine Desired Stream Location

When using the LDC method, the optimal location for developing the pollutant load allocation is a currently monitored SWQM station located near the outlet of the watershed. SWQM Station 11335 (Figure 11) is the only location within the TMDL subwatershed where an adequate number of *E. coli* data have been collected and is located at the watershed outlet. The 34 *E. coli* sampling results for Station 11335 collected over a period from February 2012 to February 2020 and during the 10-year hydrologic period were determined to be adequate to develop pollutant load allocations and exceed the minimum of 24 samples suggested in Jones et al. (2009).

3.3.3. Step 3: Develop Drainage-Area Ratio Parameter Estimates

Once the hydrologic period of record and station location were determined, the next step was to develop the 10-year daily streamflow record for TCEQ SWQM Station 11335 in the Caney Creek watershed. The daily streamflow records were developed from extant USGS records.

The method to develop the necessary streamflow record for the FDC/LDC location (SWQM station location) involved a DAR approach. The DAR approach involves multiplying a USGS gaging station daily streamflow value by a factor to estimate the flow at a desired SWQM station location. The factor is determined by dividing the drainage area upstream of the appropriate monitoring station by the drainage area upstream of the USGS gauge (Table 10). Unique to this project is the fact that the gauged watershed is the same exact watershed as the station watershed (Figure 11); thus, no adjustment to the streamflow record is needed and the DAR is equal to 1.0 (Table 10).

Because an assumption of the DAR approach is similarity of hydrologic response based on commonality of landscape features such as geology, soils, and land cover, point source derived flows from within the USGS gauge watershed should first be removed from the flow record prior to application of the ratio. In practice, this complication was addressed by determining the average discharge for each of the WWTFs located above the Caney Creek USGS gauge. The average discharge for each WWTF was computed by averaging the data obtained from the EPA Enforcement and Compliance History Online database (EPA, 2021). The WWTF discharge averages were summed and then subtracted from the Caney Creek USGS daily record.

3.3.4. Step 4: Develop Daily Streamflow Records at Desired Location

In addition to the WWTF discharges, surface water diversions associated with water rights permits have the potential of impacting stream hydrology when applying the DAR approach. A spatial query of water rights features (diversions, withdrawals, return flows) revealed that the TMDL subwatershed did not contain any active water rights permits in the TMDL subwatershed. Ten active water rights permits were located in the TMDL watershed upstream of the USGS gauge 08068390 (TCEQ, 2021b). A review of the water use in the Texas Water Rights Viewer (TCEQ, 2021b) indicates that there were no recent water diversions in either watershed. Therefore, diversions associated with water rights permits were not considered in the development of the streamflow record.

After removing the average daily WWTF discharge values from the daily streamflow gauge record, each daily flow record was multiplied by the DAR. Following application of the DAR, the full permitted flows from WWTFs located within the TMDL watershed (Table 4) were added to the streamflow record along with future growth (FG) flows (calculated in Section 4.7.4) that account for the probability that additional flows from WWTF discharges may occur as a result of population increases.

Table 10. DAR for the TMDL watershed based on the drainage area of the Caney Creek USGS gauge

Water Body	Gauge/Station	Drainage Area (acres)	DAR
Caney Creek	USGS Gauge 08070500	67,002	1.0
Caney Creek	Station 11335	67,002	1.0

3.3.5. Steps 5–7: Flow Duration and Load Duration Curves Method

FDCs and LDCs are graphs indicating the percentage of time during which a value of flow or load is equaled or exceeded. To develop an FDC for a location, all of the following steps were taken in the order shown:

- Order the daily streamflow data for the location from highest to lowest and assign a rank to each data point (one for the highest flow, two for the second highest flow, and so on).
- Compute the percentage of days each flow was exceeded by dividing each rank by the total number of data point plus one.
- Plot the corresponding flow data against exceedance percentages.

Further, when developing an LDC:

- Multiply the streamflow in cubic feet per second (cfs) by the appropriate water quality criterion for *E. coli* (geometric mean of 126 cfu/100 mL) and by a conversion factor (2.44658×10^9), which gives a loading in units of cfu/day.

- Plot the exceedance percentages, which are identical to the value for the streamflow data points, against geometric mean criterion of *E. coli*.

The resulting curve represents the maximum allowable daily loadings for the geometric mean criterion. The next step was to plot the sampled *E. coli* data on the developed LDC using the following two steps:

- Compute the daily loads for each sample by multiplying the measured *E. coli* concentrations on a particular day by the corresponding streamflow on that day and the conversion factor (2.44658×10^9).

- Plot on the LDC the load for each measurement at the exceedance percentage for its corresponding streamflow.

The plots of the LDC with the measured loads (*E. coli* concentration multiplied by the daily streamflow) display the frequency and magnitude that measured loads exceed the maximum allowable loadings for the geometric mean criterion. Measured loads that are above a maximum allowable loading curve indicate an exceedance of the water quality criterion, while those below a curve show compliance.

3.4. Flow Duration Curve for the TMDL Watershed

The FDC was developed for TCEQ Station 11335 within the TMDL subwatershed (Figure 12). For this report, the FDC was developed by applying the DAR method using the Caney Creek USGS gauge 10-year period of record described in the previous sections. Flow exceedances less than 30% typically represent streamflow influenced by storm runoff while higher flow exceedances represent receding hydrographs after a runoff event, base flow, and no flow conditions.

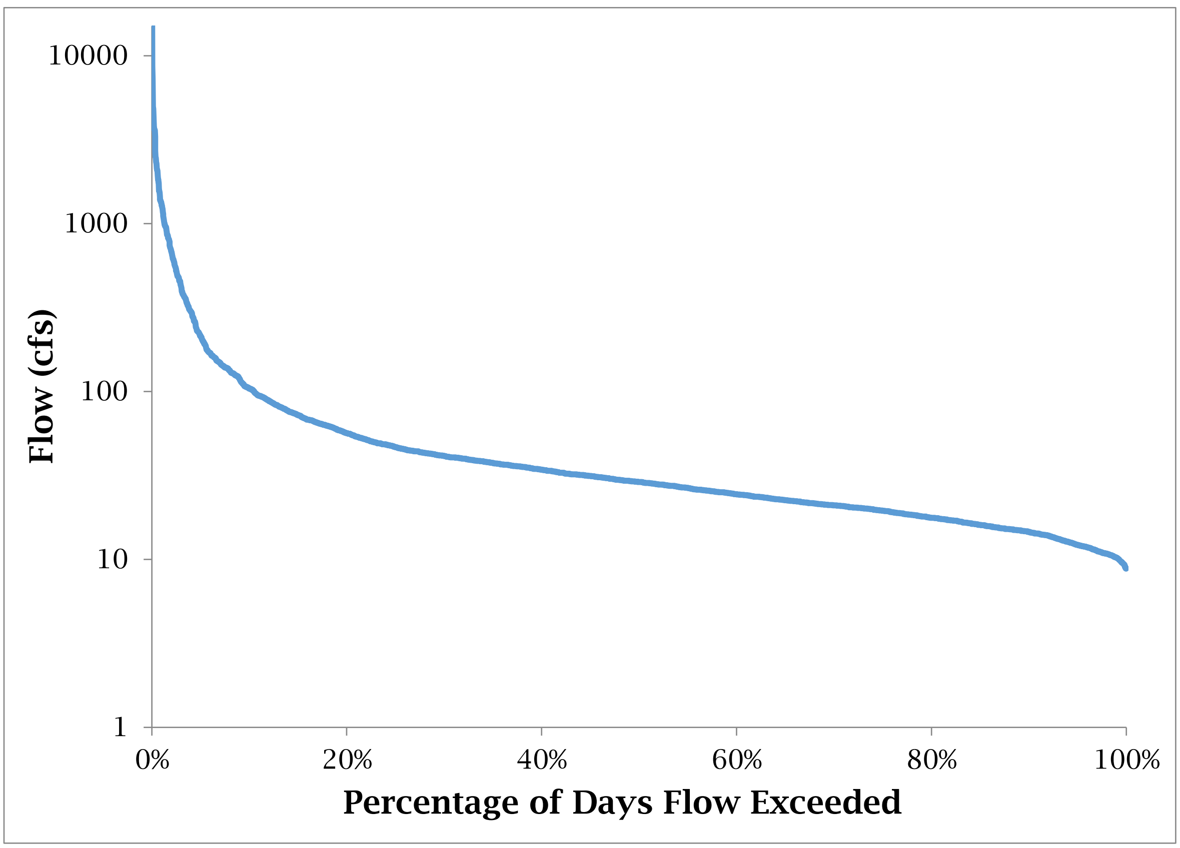

Figure 12. FDC for Caney Creek AU 1010_03 (Station 11335)

3.5. Load Duration Curve for the TMDL Watershed

An LDC was developed for TCEQ Station 11335 within the TMDL watershed (Figure 13). A useful refinement of the LDC approach is to divide the curve into flow-regime regions to analyze exceedance patterns in smaller portions of the duration curve. This approach can assist in determining streamflow conditions under which exceedances are occurring.

For Station 11335 within the TMDL watershed, streamflow distribution was divided into three flow regimes: Wet, Moderate, and Dry conditions, which maintains consistency with the previously completed TMDLs (TCEQ, 2011, 2013, 2019, and 2020b). Wet conditions correspond to large storm-induced runoff events. Moderate conditions typically represent periods of medium base flows but can also represent small runoff events and periods of flow recession following large storm events. Dry conditions represent relatively low flow conditions, resulting from extended periods of little or no rainfall and are maintained primarily by WWTF flows (Table 11).

Table 11. Flow regime classifications

Flow Regime Classification	Flow Exceedance Percentile
Wet Conditions	0 – 30%
Moderate Conditions	30 – 70%
Dry Conditions	70 – 100%

The LDC with these three flow regimes for Caney Creek AU 1010_03 is provided in Figure 13 and was constructed for developing the TMDL allocation for the TMDL subwatershed. Geometric mean loadings for the data points within each flow regime have also been distinguished on the figure to aid interpretation. The LDC for the SWQM station provides a means of identifying the streamflow conditions under which exceedances in *E. coli* concentrations have occurred. The LDC depicts the allowable loadings at the station under the geometric mean criterion (126 cfu/100 mL) and shows that existing loadings often exceed the criterion. In addition, the LDC also presents the allowable loading at the station under the single sample criterion (399 cfu/100 mL).

On the graph, the measured *E. coli* data are presented as associated with a “wet weather event” or a “non-wet weather event.” A sample was determined to be influenced by a wet weather event based on the reported “days since last precipitation” (DSLP) as noted on field data sheets associated with each sampling event. DSLP (TCEQ water quality parameter code 72053) is a field parameter that may be noted during a sampling event to inform of the general climatic and hydrologic conditions. A sample taken with a DSLP ≤ 3 days was defined as a wet weather event. Note that a wet-weather event can be indicated even under low flow conditions for only a small runoff event during a period of very low base flow in the stream.

The *E. coli* event data plotted on the LDC for Station 11335 in Figure 13 show a subtle pattern of increasing tendency for the *E. coli* event data to plot below the geometric mean criterion allowable loading curve as flows decrease, which is indicated in a left to right direction along the graph. This pattern of decreasing occurrence of exceedances in the event data are summarized by the geometric means of the existing data plotted for each of the three flow regimes as compared to the allowable load line for the geometric mean criterion.

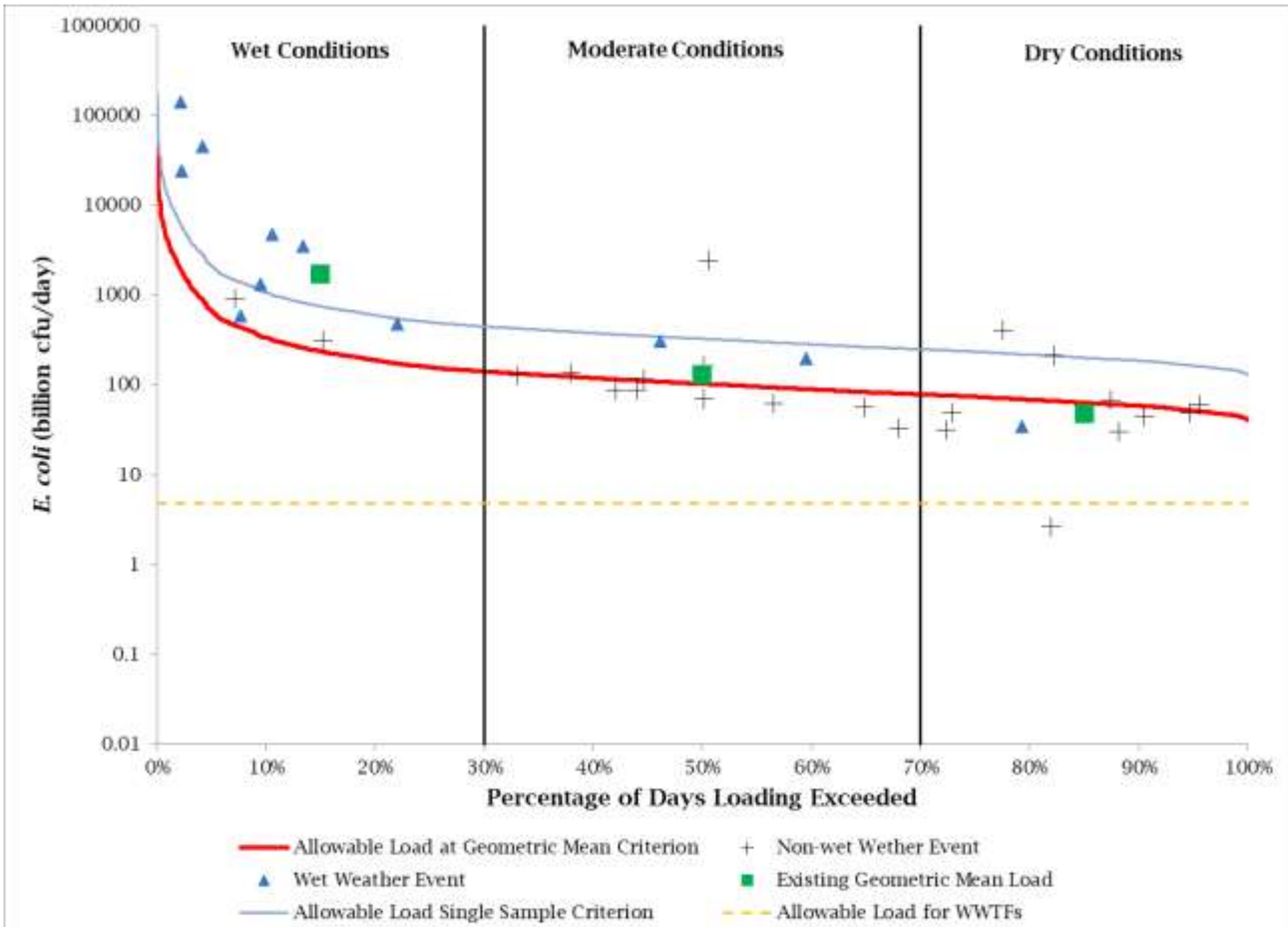

Figure 13. LDC for Caney Creek AU 1010_03 (Station 11335)

Section 4. TMDL Allocation Analysis

4.1. Endpoint Identification

All TMDLs must identify a quantifiable water quality target that indicates the desired water quality condition and provides a measurable goal for the TMDL. The TMDL endpoint also serves to focus the technical work to be accomplished and as a criterion against which to evaluate future conditions.

The endpoint for the TMDL is to maintain the concentration of *E. coli* below the geometric mean criterion of 126 cfu/100mL, which is protective of the primary contact recreation 1 use in freshwater. This endpoint was applied to the AU addressed with this TMDL.

4.2. Seasonal Variation

Seasonal variations occur when there is a cyclic pattern in streamflow and, more importantly, in water quality constituents. TMDLs must account for seasonal variation in watershed conditions and pollutant loading, as required by federal regulations [Title 40, Code of Federal Regulations (40 CFR) 130.7(c)(1)]. Analysis of the seasonal differences in indicator bacteria concentrations were assessed by comparing available *E. coli* concentrations obtained from routine monitoring collected at one SWQM station (11335). Differences in *E. coli* concentrations were evaluated by performing a Wilcoxon Rank Sum test. *E. coli* concentrations during warmer months (May – September) were compared against those during the cooler months (November – March). April and October are considered transitional periods between warm and cool seasons and therefore were excluded from the analysis. This analysis of *E. coli* data indicated that there was no significant difference (α=0.05) in indicator bacteria between cool and warm weather seasons for Caney Creek AU 1010_03 (p=0.9145).

4.3. Linkage Analysis

Establishing the relationship between instream water quality and the source of loadings is an important component in developing a TMDL. It allows for the evaluation of management options that will achieve the desired endpoint. The relationship may be established through a variety of techniques.

Generally, if high bacteria concentrations are measured in a water body at low to median flow in the absence of runoff events, the main contributing sources are likely to be point sources and direct deposition (such as direct fecal deposition into the water body). During ambient flows, these inputs to the system will increase pollutant concentrations depending on the magnitude and concentration of the sources. As flows increase in magnitude, the impact of point sources and direct deposition is typically diluted, and would, therefore, be a smaller part of the overall concentrations.

Bacteria load contributions from regulated and unregulated stormwater sources are greatest during runoff events. Rainfall runoff, depending upon the severity of the storm, has the capacity to carry indicator bacteria from the land surface into the receiving stream. Generally, this loading follows a pattern of higher concentrations in the water body as the first flush of storm runoff enters the receiving stream. Over time, the concentrations decline because the sources of indicator bacteria are attenuated as runoff washes them from the land surface and the volume of runoff decreases following the rain event.

LDCs were used to examine the relationship between instream water quality and the source of indicator bacteria loads. Inherent to the use of LDCs as the mechanism of linkage analysis is the assumption of a direct relationship between pollutant load sources (regulated and unregulated) and instream loads. Further, this one-to-one relationship was also inherently assumed when using LDCs to define the TMDL pollutant load allocation (Section 4.7.). That allocation was based on the flows associated with the watershed areas under stormwater regulation, and the remaining portion was assigned to the unregulated stormwater.

4.4. Load Duration Curve Analysis

LDC analyses were used to examine the relationship between instream water quality and the broad sources of indicator bacteria load, and they are the basis of the TMDL allocation. The strength of this TMDL is the use of the LDC method to determine the TMDL allocation. An LDC is a simple statistical method that provides a basic description of the water quality problem. This tool is easily developed and explained to stakeholders and uses available water quality and flow data. The LDC method does not require any assumptions regarding loading rates, stream hydrology, land use conditions, and other conditions in the watershed. The EPA supports the use of this approach to characterize pollutant sources. In addition, many other states are using this method to develop TMDLs. As discussed in more detail in Section 4.7. (Pollutant Load Allocation), the TMDL load was based on the median flow within the wet-conditions flow regime (or 15% load duration exceedance), where exceedances to the primary contact recreation 1 use criteria are most pronounced.

The weaknesses of this method include the limited information it provides about the magnitude or specific origin of the various sources. Information gathered about point and nonpoint sources in the watershed is limited. The general difficulty in analyzing and characterizing *E. coli* in the environment is also a weakness of this method.

The LDC method allows for estimation of existing and allowable TMDL loads by utilizing the cumulative frequency distribution of streamflow and measured pollutant concentration data (Cleland, 2003). In addition to estimating stream loads, this method allows for the determination of the hydrologic conditions under which impairments are typically occurring, can give indications of the broad origins of the bacteria (i.e., point source and stormwater), and provides a means to allocate allowable loadings.

Based on the LDC used in the pollutant load allocation process with historical *E. coli* data added to the graph (Figure 13) and Section 2.7 (Potential Sources of Fecal

Indicator Bacteria), the following broad linkage statements can be made. For the TMDL watershed, the historical *E. coli* data indicate that elevated bacteria loadings occur under all three flow regimes, especially during high flows. There is some moderation of the elevated loadings under moderate and dry conditions for the TMDL subwatershed. On Figure 13, the geometric means of the measured data for each flow regime generally support the observation of decreasing concentration with decreasing flow, and under dry conditions the data indicate the geometric mean is below the geometric mean criterion (126 cfu/100 mL).

4.5. Margin of Safety

The margin of safety (MOS) is used to account for uncertainty in the analysis performed to develop the TMDL and thus provides a higher level of assurance that the goal of the TMDL will be met. According to EPA guidance (EPA, 1991), the MOS can be incorporated into the TMDL using either of the following two methods:

1. Implicitly incorporating the MOS using conservative model assumptions to develop allocations.
2. Explicitly specifying a portion of the TMDL as the MOS and using the remainder for allocations.

The MOS is designed to account for any uncertainty that may arise in specifying water quality control strategies for the complex environmental processes that affect water quality. Quantification of this uncertainty, to the extent possible, is the basis for assigning an MOS.

The TMDL in this report incorporates an explicit MOS of 5%.

4.6. Load Reduction Analysis

While the TMDL for the Caney Creek AU 1010_03 watershed was developed using an LDC and associated load allocations, additional insight may, in certain situations, be gained through a load reduction analysis. A single percentage load reduction required to meet the allowable loading for each of the three flow regimes was determined using the historical *E. coli* data obtained from the SWQM station within the impaired water body.

For each flow regime the percentage reduction required to achieve the geometric mean criterion was determined by calculating the difference in the existing (or measured) geometric mean concentration and the 126 cfu/100 mL criterion and dividing that difference by the existing geometric mean concentration (Table 12).

Table 12. Percentage reduction calculations for TCEQ Station 11335

Flow Regime	Number of Samples	Geometric Mean by Flow Regime (cfu/100mL)	Required Percentage Reduction by Flow Regime
Wet Conditions (0–30%)	10	908	86.1%
Moderate Conditions (30–70%)	13	159	20.8%
Dry Conditions (70–100%)	11	95	0%

4.7. Pollutant Load Allocations

A TMDL represents the maximum amount of a pollutant that the water body can receive in a single day without exceeding water quality standards. The pollutant load allocations for the selected scenarios were calculated using the following basic equation:

TMDL = WLA + LA + FG + MOS (Equation 1)

Where:

WLA = wasteload allocation, the amount of pollutant allowed by regulated dischargers

LA = load allocation, the amount of pollutant allowed by unregulated sources

FG = loadings associated with future growth from potential regulated facilities

MOS = margin of safety load

TMDLs can be expressed in terms of mass per time, toxicity, or other appropriate measures [40 CFR, 130.2(i)]. For *E. coli*, TMDLs are expressed as billion cfu/day and represent the maximum one-day load the stream can assimilate while still attaining the standards for surface water quality.

4.7.1. Assessment Unit-Level TMDL Calculations

The bacteria TMDL for AU 1010_03 was developed based on information from the LDC for TCEQ Station 11335 (Figure 13). As discussed in more detail in Section 3, the bacteria LDC was developed by multiplying each flow value along the FDC by the *E. coli* criterion (126 cfu/100 mL) and by the conversion factor used to represent maximum loading in cfu/day. Effectively, the “Allowable Load” displayed in the LDC at 15% exceedance (the median value of the wet conditions-flow regime) is the TMDL:

TMDL (cfu/day) = Criterion * Flow (cfs) * Conversion Factor (Equation 2)

Where:

Criterion = 126 cfu/100 mL (*E. coli*)

Conversion Factor (to billion cfu/day) = (28,316.846 mL/cubic feet * 86,400 seconds/day) ÷ 1,000,000,000

The allowable loading of *E. coli* that the impaired watershed can receive daily was determined using Equation 2 based on the median value within the wet-conditions flow regime of the FDC (or 15% flow exceedance value) for the SWQM station (Table 13).

Table 13. Summary of allowable loading calculation

Water Body	AU	15% Exceedance Flow (cfs)	15% Exceedance Load (Billion cfu/day)	TMDL (Billion cfu/day)
Caney Creek	1010_03	77.024	237.441	237.441

4.7.2. Margin of Safety Allocation

The MOS is only applied to the allowable loading for a watershed. Therefore, the MOS is expressed mathematically as the following:

$$MOS = 0.05 * TMDL \qquad \text{(Equation 3)}$$

Using the value of TMDL for the AU provided in Table 13, the MOS may be readily computed by proper substitution into Equation 3 (Table 14).

Table 14. MOS calculations

Load units expressed as billion cfu/day *E. coli*

Water Body	AU	TMDL[a]	MOS
Caney Creek	1010_03	237.441	11.872

[a] TMDL from Table 13.

4.7.3. Wasteload Allocations

The WLA consists of two parts — the wasteload that is allocated to TPDES-regulated WWTFs (WLA_{WWTF}) and the wasteload that is allocated to regulated stormwater dischargers (WLA_{SW}).

$$WLA = WLA_{WWTF} + WLA_{SW} \qquad \text{(Equation 4)}$$

4.7.3.1. Wastewater

TPDES-permitted WWTFs are allocated a daily wasteload calculated as their full permitted discharge flow rate multiplied by one-half the instream geometric criterion. One-half of the water quality criterion (63 cfu/100mL) is used as the WWTF target to provide instream and downstream load capacity, and to be consistent with previously developed TMDLs. Thus, WLA_{WWTF} is expressed in the following equation:

$$WLA_{WWTF} = Target * Flow * Conversion\ Factor \qquad \text{(Equation 5)}$$

Where:

Target= 63 cfu/100 mL

Flow = full permitted flow (MGD)

Conversion Factor (to billion cfu/day) = 3,785,411,800 mL/million gallons ÷ 1,000,000,000

Using this equation, each WWTF's allowable loading was calculated using the permittee's full permitted flow. Table 15 presents the WLA for each WWTF and the resulting total allocation for the AU within the TMDL watershed.

Table 15. WLAs for TPDES-permitted facilities

Load units expressed as billion cfu/day *E. coli*

AU	TPDES Permit	NPDES Permit	Permittee	Full Permitted Flow (MGD)[a]	*E. coli* WLA_{WWTF}
1010_03	WQ0012204001	TX0083216	Conroe ISD	0.02	0.048
1010_03	WQ0014285001	TX0124281	C & R Water Supply Inc.	0.30	0.715
1010_03	WQ0015261001	TX0135453	Crystal Springs Water Co., Inc.	0.325	0.775
1010_03	WQ0015689001	TX0138568	Crockett Martin Corp.	0.025	0.060
1010_03	WQ0016005001	TX0141399	Crystal Springs Water Co., Inc.	0.75	1.789
1010_01	WQ0011020001	TX0056685	City of New Waverly	0.088	0.210
1010_01	WQ0011020002	TX0087831	City of New Waverly	0.10	0.238
1010_02	WQ0011715001	TX0068659	Texas National MUD	0.225	0.537
1010_02	WQ0012670001	TX0092517	Quadvest, L.P.	0.175	0.417
1010_02	WQ0015984001	TX0141224	Texas Campgrounds Club, Inc.	0.04	0.095
Total				2.048	4.884

[a] Full Permitted Flow from Table 4.

4.7.3.2. Regulated Stormwater

Stormwater discharges from MS4, industrial, and construction areas are considered regulated point sources. Therefore, the WLA calculations must also include an allocation for regulated stormwater discharges. A simplified approach for estimating the WLA for these areas was used in the development of this TMDL due to the limited amount of data available, the complexities associated with simulating rainfall runoff, and the variability of stormwater loading.

The percentage of the land area included in the TMDL watershed that is under the jurisdiction of stormwater permits is used to estimate the amount of the overall runoff load that should be allocated as the permitted stormwater contribution in the WLA_{SW} component of the TMDL. The LA component of the TMDL corresponds to direct nonpoint runoff and is the difference between the total load from stormwater runoff and the portion allocated to WLA_{SW}.

WLA_{SW} is the sum of loads from regulated stormwater sources and is calculated as follows:

$$WLA_{SW} = (TMDL - WLA_{WWTF} - FG - MOS) * FDA_{SWP} \quad \text{(Equation 6)}$$

Where:

TMDL = total maximum daily load

WLA_{WWTF} = sum of all WWTF loads

FG = sum of future growth loads from potential regulated facilities

MOS = margin of safety load

FDA_{SWP} = fractional proportion of drainage area under jurisdiction of stormwater permits

The fractional proportion of the drainage area under the jurisdiction of stormwater permits (FDA_{SWP}) must be determined to estimate the amount of overall runoff load that should be allocated to WLA_{SW}. The term FDA_{SWP} was calculated based on the combined area under regulated stormwater permits within the TMDL watershed. As described in Section 2.7.1.5, a search for all five categories of stormwater general permits was performed. The search results are presented in Table 16.

A portion of the TMDL watershed lies within the jurisdiction of two MS4 phase II authorizations. Two MSGP authorizations, 17 construction authorizations, and one concrete production facility exist within the TMDL watershed. For this TMDL, the acreage associated with the MSGP authorizations and the concrete production facility was estimated by importing the location information associated with the facilities into a geographic information system, and measuring the estimated disturbed area based on the most recently available aerial imagery. Additionally, the areas disturbed associated with each of the 17 construction authorizations within the TMDL watershed were summed. The area associated with the 2010 Conroe/Woodlands urbanized area along with the areas associated with the MSGP authorizations, concrete production facility, and construction authorizations located within the TMDL watershed provide stormwater coverage for Caney Creek AU 1010_03.

Table 16. Stormwater general permit areas and calculation of the FDA_{SWP} term

Water Body	MS4 General Permit (acres)	MSGP (acres)	Construction Activities (acres)	Concrete Production Facilities (acres)	Total Area of Permits (acres)	Watershed Area (acres)	FDA_{SWP}
Caney Creek (TMDL Watershed)	2,607	49	1,608	55	4,319	67,002	0.0645

The daily allowable loading of *E. coli* assigned to WLA_{SW} was determined based on the combined area under regulated stormwater permits. To calculate the WLA_{SW} (Equation 6), the FG term must be known. The calculation for the FG term is presented in the next section, but the results will be included here for continuity. Table 17 provides the information needed to compute WLA_{SW}.

Table 17. Regulated stormwater calculations

Load units expressed as billion cfu/day *E. coli*

Water Body	AU	TMDL[a]	MOS[b]	WLA_{WWTF}[c]	FG[d]	FDA_{SWP}[e]	WLA_{SW}[f]
Caney Creek (TMDL watershed)	1010_03	237.441	11.872	4.884	19.489	0.0645	12.977

[a] TMDL from Table 13

[b] MOS from Table 14

[c] WLA_{WWTF} from Table 15

[d] FG from Table 18

[e] FDA_{SWP} from Table 16

[f] $WLA_{SW} = (TMDL - WLA_{WWTF} - FG - MOS) * FDA_{SWP}$ (Equation 6)

4.7.4. Future Growth

The FG component of the TMDL equation addresses the requirement to account for future loadings that may occur due to population growth, changes in community infrastructure, and development. Specifically, this TMDL component takes into account the probability that new flows from WWTF discharges may occur in the future. The assimilative capacity of water bodies increases as the amount of flow increases.

The allowance for FG will result in protection of existing uses and conform to Texas' antidegradation policy.

While the FG allowance is often computed for bacteria TMDLs using information from existing WWTF permits, it is not intended to restrict any future assignments of the allocation solely to expansions at these facilities. Rather, the FG allocation is purposed for any new facilities that may occur and expansions of existing facilities. This definition of FG is relevant as three WWTFs (Crocket Martin Estates MHC, Crystal Springs Water Co., and Texas Campgrounds Club Inc.) are active but not operational. The proposed facilities, while active, have not been developed at the time of this report with limited information available; however, full permitted flow data were available. Thus, the WWTFs were considered as currently permitted and operating.

The FG component of the TMDL watershed was based on population projections and current permitted wastewater dischargers for the entire TMDL watershed. Recent population and projected population growth between 2010 and 2070 for the TMDL watershed are provided in Table 2. The projected population percentage increase within the watershed was multiplied by the corresponding WLA_{WWTF} to calculate future

WLA_{WWTF}. The permitted flows were increased by the expected population growth per AU between 2010 and 2070 to determine the estimated future flows.

Thus, the FG is calculated as follows:

$$FG = WWTF_{FP} * POP_{2010-2070} * \text{Conversion Factor} * \text{Target} \quad \text{(Equation 7)}$$

Where:

$WWTF_{FP}$ = full permitted WWTF discharge (MGD)

$POP_{2010-2070}$ = estimated percentage increase in population between 2010 and 2070

Conversion Factor = (37,854,000 100mL/MGD) ÷ 1,000,000,000

Target = 63 cfu/100 mL

The calculation results for the impaired TMDL watershed are shown in Table 18.

Table 18. FG calculation

Water Body	AU	Full Permitted Flow (MGD)	% Population Increase (2010–2070)	FG (MGD)	FG (*E. coli* Billion cfu/day)[a]
Caney Creek (TMDL watershed)	1010_03	2.048	399.0%	8.172	19.489

[a] $FG = WWTF_{FP} * POP_{2010-2070}$ * conversion factor * target (Equation 7)

4.7.5. Load Allocations

The load allocation (LA) is the load from unregulated sources, and is calculated as:

$$LA = TMDL - WLA_{WWTF} - WLA_{SW} - FG - MOS \quad \text{(Equation 8)}$$

Where:

TMDL = total maximum daily load

WLA_{WWTF} = sum of all WWTF loads

WLA_{SW} = sum of all regulated stormwater loads

FG = sum of future growth loads from potential regulated facilities

MOS = margin of safety load

The calculation results are shown in Table 19.

Table 19. LA calculation

Load units expressed as billion cfu/day *E. coli*

Water Body	AU	TMDL[a]	MOS[b]	WLA_{WWTF}[c]	WLA_{SW}[d]	FG[e]	LA[f]
Caney Creek (TMDL watershed)	1010_03	237.441	11.872	4.884	12.977	19.489	188.219

[a] TMDL from Table 13

[b] MOS from Table 14

[c] WLA_{WWTF} from Table 15

[d] WLA_{SW} from Table 17

[e] FG from Table 18

[f] LA = TMDL - WLA_{WWTF} - WLA_{SW} - FG - MOS (Equation 8)

4.8. Summary of TMDL Calculations

Table 20 summarizes the TMDL calculation for the TMDL watershed. The TMDL was calculated based on the median flow in the 0–30 percentile range (15% exceedance, wet-conditions flow regime) for flow exceedance from the LDC developed for SWQM Station 11335. Allocations are based on the current geometric mean criterion for *E. coli* of 126 cfu/100 mL for each component of the TMDL.

Table 20. TMDL allocation summary

Load units expressed as billion cfu/ day *E. coli*

Water Body	AU	TMDL[a]	MOS[b]	WLA_{WWTF}[c]	WLA_{SW}[d]	LA[e]	FG[f]
Caney Creek (TMDL watershed)	1010_03	237.441	11.872	4.884	12.977	188.219	19.489

[a] TMDL from Table 13

[b] MOS from Table 14

[c] WLA_{WWTF} from Table 15

[d] WLA_{SW} from Table 17

[e] LA from Table 19

[f] FG from Table 18

The final TMDL allocation (Table 21) needed to comply with the requirements of 40 CFR 130.7 include the FG component within the WLA_{WWTF}.

Table 21. Final TMDL allocation

Load units expressed as billion cfu/ day *E. coli*

Water Body	AU	TMDL	MOS	WLA_{WWTF}[a]	WLA_{SW}	LA
Caney Creek (TMDL watershed)	1010_03	237.441	11.872	24.373	12.977	188.219

[a] WLA_{WWTF} includes the FG component

Section 5. References

AVMA (American Veterinary Medical Association). 2018. 2017–2018 U.S. Pet Ownership Statistics, retrieved July 1, 2021, from: www.avma.org/resources-tools/reports-statistics/us-pet-ownership-statistics.

Cleland, B. 2003. TMDL Development From the "Bottom Up" — Part III: Duration Curves and Wet-Weather Assessments. Retrieved July 19, 2021 from: www.engineering.purdue.edu/mapserve/ldc/pldc/help/TMDL_Development_from_the_Bottom_UP_PartIV.pdf.

eBird. 2021. eBird: An online database of bird distribution and abundance [web application]. Ithaca, NY. Retrieved July 1, 2021, from: ebird.org/home.

EPA. 1991. Guidance for Water Quality-Based Decisions: The TMDL Process. Retrieved July 19, 2021, from Office of Water: Total Maximum Daily Loads (303d): www.epa.gov/sites/default/files/2018-10/documents/guidance-water-tmdl-process.pdf.

EPA. 2007. An Approach for Using Load Duration Curves in the Development of TMDLs. EPA 841-B-07-006. www.epa.gov/sites/production/files/2015-07/documents/2007_08_23_tmdl_duration_curve_guide_aug2007.pdf.

EPA. 2021. Enforcement and Compliance History Online (ECHO). Retrieved May 20, 2021 from: echo.epa.gov/.

Jones, C. A., Wagner, K., Di Giovanni, G., Hauck, L., Mott, J., Rifai, H., Srinivasan, R., Ward, G., Wythe, K. 2009. Bacteria Total Maximum Daily Load Task Force Final Report (No. TR-341). TWRI. Retrieved July 02, 2021, from: https://www.researchgate.net/publication/26903717_Bacteria_Total_Maximum_Daily_Load_Task_Force_Report.

Larkin, Thomas J., G. Bomar. 1983. Climatic Atlas of Texas. LP-192. Texas Department of Water Resources. Retrieved June 18, 2021, from: www.twdb.texas.gov/publications/reports/limited_printing/doc/LP192.pdf.

NEIWPCC (New England Interstate Water Pollution Control Commission). 2003. Illicit Discharge Detection and Elimination Manual. Retrieved July 19, 2021 from: www.neiwpcc.org/neiwpcc_docs/iddmanual.pdf.

NOAA. 2021. Station USW00053902, Conroe North Houston Regional Airport TX, US. Retrieved June 18, 2021, from National Climatic Data Center: www.ncdc.noaa.gov/cdo-web/search.

NRCS. 2019. Gridded Soil Survey Geographic Database for Montgomery and Walker Counties. Retrieved June 23, 2021, from: datagateway.nrcs.usda.gov/.

Reed, Stowe, and Yanke, LLC. 2001. Study to Determine the Magnitude of, and Reasons for, Chronically Malfunctioning On-site Sewage Facility Systems in Texas. Retrieved July 18, 2021 from: www.tceq.texas.gov/assets/public/compliance/compliance_support/regulatory/ossf/StudyToDetermine.pdf.

TCEQ. 2007. 2006 Texas Water Quality Inventory and 303(d) List (since 2010, referred to as the Texas Integrated Report). Available online at: www.tceq.texas.gov/waterquality/assessment/06twqi/twqi06.html

TCEQ. 2011. Fifteen Total Maximum Daily Loads for Indicator Bacteria in Watersheds Upstream of Lake Houston. Available online at: www.tceq.texas.gov/assets/public/waterquality/tmdl/82lakehouston/82-lakehoustontmdl_adopted.pdf Accessed May 10, 2021.

TCEQ. 2013. Addendum One to Fifteen Total Maximum Daily Loads for Indicator Bacteria in Watersheds Upstream of Lake Houston: Six Total Maximum Daily Loads for Indicator Bacteria in Watersheds Upstream of Lake Houston. Available online at: www.tceq.texas.gov/assets/public/waterquality/tmdl/82lakehouston/82A-LakeHoustonAddendum1.pdf Accessed May 10, 2021.

TCEQ. 2018a. Texas Surface Water Quality Standards, 2018, 30 TAC 307. Available online at: texreg.sos.state.tx.us/public/readtac%24ext.ViewTAC?tac_view=4&ti=30&pt=1&ch=307&rl=Y Accessed June 17, 2021.

TCEQ. 2018b. Preserving & Improving Water Quality — The Programs of the Texas Commission on Environmental Quality for Managing the Quality of Surface Waters. Retrieved June 17, 2021, from: www.tceq.texas.gov/assets/public/comm_exec/pubs/gi/gi-351.pdf.

TCEQ. 2019a. Second Submission of the 2018 Texas Integrated Report for the Clean Water Act Sections 305(b) and 303(d). Available online at: www.tceq.texas.gov/waterquality/assessment/18twqi/18txir

TCEQ. 2019b. Addendum Two to Fifteen Total Maximum Daily Loads for Indicator Bacteria in Watersheds Upstream of Lake Houston: Two Total Maximum Daily Loads for Indicator Bacteria in Brushy Creek and Spring Branch. Available online at: www.tceq.texas.gov/assets/public/waterquality/tmdl/82lakehouston/82-brushy-spring-addendum-oct2019.pdf Accessed May 10, 2021.

TCEQ. 2020a. 2020 Texas Integrated Report of Surface Water Quality for Clean Water Act Sections 305(b) and 303(d). Retrieved June 15, 2021, from: https://www.tceq.texas.gov/waterquality/assessment/20twqi.

TCEQ. 2020b. Addendum Three to Fifteen Total Maximum Daily Loads for Indicator Bacteria in Watersheds Upstream of Lake Houston: One Total Maximum Daily Load for Indicator Bacteria in Walnut Creek. Available online at: www.tceq.texas.gov/assets/public/waterquality/tmdl/82lakehouston/82-tmdl-addendum-bacteria-walnutcreek.pdf Accessed June 17, 2021.

TCEQ. 2021a. Water Quality and General Permits & Registration Search. Retrieved September 14, 2021 from: www2.tceq.texas.gov/wq_dpa/index.cfm.

TCEQ. 2021b. Texas Water Rights Viewer. Retrieved July 01, 2021, from: www.tceq.texas.gov/gis/water-rights-viewer.

Timmons J., Higginbotham B., Lopez R., Cathey J., Mellish J., Griffin J, Sumrall A., Skow, K. 2012. *Feral Hog Population Growth, Density and Harvest in Texas.* Retrieved September 14, 2021 from: agrilife.org/bexarcounty/files/2012/07/ESP-472-Feral-Hog-Population-Growth-Density-Harvest-in-Texas.pdf.

TWDB. 2019a. Population Projections by Regional Water Planning Group. 2021 Regional Water Plan Population and Water Demand Projections. Retrieved May 25, 2021 from: www.twdb.texas.gov/waterplanning/data/projections/2022/popproj.asp.

TWDB. 2019b. Complete Regional Population Projections by Water User Group in Texas. 2021 Regional Water Plan Population and Water Demand Projections. Retrieved May 25, 2021, from: www.twdb.texas.gov/waterplanning/data/projections/2022/popproj.asp.

TPWD. 2021. White-tailed Deer (WTD) Federal Aid Report 2021 Charts and Tables. Personal communication from A. Cain received April 28, 2021.

USCB. 2010. 2010 Census Block Shapefiles. Retrieved May 21, 2021, from: www.census.gov/cgi-bin/geo/shapefiles/index.php; Tabular data from 2010 Census Block Households and Families. Retrieved May 21, 2021, from: data.census.gov/cedsci/.

USDA NASS (National Agricultural Statistics Service). 2019. State and County Data, Volume 1, Part43A, Inventory and Sales (2017 Census). Retrieved July 1, 2021, from: www.nass.usda.gov/Publications/AgCensus/2017/Full_Report/Census_by_State/index.php.

USGS. 2019. National Land Cover Database 2016 Land Cover Conterminous United States, Retrieved May 11, 2021, from: www.mrlc.gov/data/nlcd-2016-land-cover-conus.

USGS. 2021. USGS Streamflow Data for Station 08070500, Caney Creek near Splendora, TX. Retrieved May 11, 2021, from: waterdata.usgs.gov/nwis/dv?referred_module=sw&site_no=08070500.

Weiskel, P., Howes, B., and Heufelder, G. 1996. Coliform Contamination of a Coastal Embayment: Sources and Transport Pathways. Environmental Science and Technology, 30, 1872–1881. Retrieved July 1, 2021, from: pubs.acs.org/doi/pdf/10.1021/es950466v.

Appendix A. Estimation of the 2010 Census population and 2070 population projections for Caney Creek AU 1010_03 Watershed

The following steps detail the method used to estimate the 2010 and projected 2070 populations in the Caney Creek AU 1010_03 TMDL watershed and subwatershed.

1) Obtained 2010 USCB data at the block level.
2) Developed the 2010 watershed population using the USCB block level data for the portions of Montgomery and Walker counties within the watershed.
3) For the census blocks that were partially located in the watershed, estimated population by multiplying the block population to the proportion of its area in the watershed.
4) Obtained the TWDB Population Projections by Regional Water Planning Group for region H. Used projections for “County-Other” to determine population increases for the rural areas in Montgomery and Walker counties from 2010 to 2070 (TWDB, 2019a).
5) Located the relevant Water User Groups (WUGs) with areas within the watershed and determined the proportion of each WUG area within the watershed (TWDB, 2019b).
6) Calculated decadal percentage increases in population using the TWDB (2019b) decadal population projections for the portion of Cut and Shoot, New Waverly, and Willis WUGs between 2010 and. This projected increase was used to estimate population projections in these cities.
7) Summed the projected population increases obtained in steps 4 and 6 to the 2010 population of the watershed to obtain population projections for the watershed out to 2070.